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THE EFFECT OF MINERAL FILLER, ASPHALT CONTENT, AND CURING TIME ON THE PROPERTIES OF COLD MIXES WHEN USED FOR LOW-VOLUME ROADS

BY

NASER A. ABDALLA

A thesis submitted
in partial fulfillment of the requirements for the
degree Master of Science
Major in Civil Engineering
South Dakota State University
1988

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THE EFFECT OF MINERAL FILLER, ASPHALT CONTENT, AND CURING TIME ON THE PROPERTIES OF COLD MIXES WHEN USED FOR LOW-VOLUME ROADS

This thesis is approved as a creditable and independent investigation by a candidate for the degree, Master of Science, and is acceptable for meeting the thesis requirements for this degree. Acceptance of this thesis does not imply that the conclusions reached by the candidate are necessarily the conclusions of the major department.

Dr. Ali A. Selim — Date
Civil Engineering Department
Thesis Advisor

Dr. Dwayne Rollag — Date
Head
Civil Engineering Department

DEDICATION

I dedicate this thesis to my sincere Mother who passed away during my senior high school year, for which it was always her wish to see me in higher education. To my dear Father and Brothers for their support, encouragement, and courageous effort.

NAS

ACKNOWLEDGEMENTS

The author wishes to express his sincere thanks and appreciation to his advisor, Dr. Ali A. Selim, Professor, Department of Civil Engineering, for his immeasurable suggestions throughout the course of this research work. His continued interest and guidance are appreciated.

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NAS

TABLE OF CONTENTS

TABLE OF CONTENTS (continued)

LIST OF FIGURES

LIST OF FIGURES (continued)

LIST OF TABLES

ABSTRACT

Factors such as economy, awareness of environmental problems, and the need for conservation of energy fuels have increased the rate of emulsion use in recent years. These factors have also shifted the efforts to replace cutback asphalts with emulsified asphalts in a majority of paving applications, especially in paving mixtures.

This study reports the findings of a laboratory investigation that evaluated the effect of asphalt emulsion content, percent of mineral filler, and curing time on the design parameters and properties of emulsified asphalt-aggregate cold mixes used in low-volume road by utilizing Marshall equipment. One aggregate type (quartzite) and one type of asphalt emulsion (CSS-1) were used. Sixty specimens were prepared and tested in accordance with the procedure developed by the Asphalt Institute utilizing the Marshall mix-design method, along with minor modifications created for this particular study. The variation of mineral filler in the mix and curing time were considered and analyzed rather than determination of an optimal residual asphalt content for a job mix.

Comparative studies were conducted using statistical analysis, and prediction models were constructed to predict cold mix properties utilizing the data obtained from the laboratory. These models revealed that mix properties cannot be evaluated in relation to a single factor, and the interaction of these factors must be considered in the

evaluation as demonstrated by various models. However, a basic finding of this study was that curing time has the greatest effect on cold mixes and increasing it tends to enhance their properties a great deal.

CHAPTER 1

INTRODUCTION

The Asphalt Institute has adopted a method for emulsified asphalt-aggregate mix design. This method is reproduced with minor changes from the "Interim Guide to Full-Depth Asphalt Paving Using Various Asphalt Mixes", PCD-1, The Asphalt Institute, January 1976. Yet, the Marshall Method for Emulsified Asphalt-Aggregate Cold Mix Design is widely used in the Midwest region of the United States and is based on research conducted at the University of Illinois using a modified Marshall method of mix design and a moisture durability test; the procedures contain modifications suggested by NCHRP Report 259, "Design of Emulsified Asphalt Paving Mixtures".

Unlike hot asphalt mixes, emulsified asphalt-aggregate mixes are prepared at ambient temperatures. For this reason the procedure followed differs in part from that of a hot mix. Moreover, the procedures followed for cold mixes differ and vary from one method to another. As a matter of fact, there is no foolproof methodology for cold mix design. That might be blamed on lack of research and full understanding of the behavior of cold mixes, besides the variety of factors that affect cold mixes and contribute a great deal to the selection of the types of emulsions and aggregates that best fit the job. For the foregoing reasons, and for the sake of new research, the procedure followed throughout this study is somewhat different from any single method mentioned earlier, but is greatly based on the procedures of both methods.

It should be pointed out that some of the similarities and differences of the two methods are as shown below:

<u>The Asphalt Institute Method</u>

1. Selection of the approximate emulsified asphalt content is exclusively dependent on the Centrifuge Kerosene Equivalent (C.K.E.) method.

2. Determination of premixing water added is done by the visual observation of coating, workability of mix, and runoff analysis.

3. The optimum water content at compaction is determined by a water content versus dry density analysis and is also related to specimen fabrication.

4. Stability testing utilizes a Resistance-R value test, Stabilometer-S value test, and a Cohesiometer test.

5. The curing time of specimens must be determined by a Resilient Modulus (MR) test which is performed on specimens that have been cured for 3 days in air at room temperature and vacuum desiccated for 4 to 5 days at 10 to 20 mm of Hg.

6. A kneeding compactor, followed by a double plunger static load at 40,000 lb (178 KN), is utilized for compaction.

The Marshall Mix Design Method

1. The approximate amount of emulsified asphalt for trial mixes is determined by either the C.K.E. method or the formula presented later in paragraph (3.1) of this study.
2. Determination of premixing water added is done only by a visual observation of the aggregate coating.
3. The optimum water content at compaction is selected through an analysis of water content versus dry Marshall stability.
4. Stability testing utilizes a Marshall testing machine.
5. The curing time of specimens is recommended to be 1 day in the mold at room temperature and 1 day out of the mold in an oven at 100° F (38° C).
6. A compaction pedestal consisting of an 8 x 8 x 18 in. wooden post capped with a 12 x 12 x 1 in. steel plate is used for compacting the specimens.

The method followed throughout this study involves new ways of performing the test on cold mixes, such as the way of determining the bulk specific gravity of the compacted mix, paragraph (3.3.3). The approach followed intended to yield more accurate and dependable results.

1.1 Description of Emulsion Mixtures

The rate of emulsion use has accelerated considerably in recent years (9). The consideration of road building costs, the greater awareness of the environmental problems, and the need for conservation of energy fuels greatly influenced this new growth. Because of these factors, the current trends are to replace cutback asphalts with emulsified asphalts in a majority of paving applications. For the foregoing reasons, the use of emulsified asphalt paving mixtures employing dense-graded mineral aggregates, also increased in recent years. Such mixtures are used for many types of pavements ranging from surface courses of low-volume rural roads to base courses of high volume highways.

Design of emulsion paving mixtures presents a significant challenge for the designer, because such mixes are far more complex than either hot mixes or paving mixtures with cutback asphalt. Emulsion mixtures are three-component systems containing mineral aggregate, asphalt, and water. Asphalt concrete or cutback mixtures, on the other hand, contain aggregate and organic binder, a two-component system. Water in emulsion mixtures may come from three sources: water absorbed by the mineral aggregate, water added to the aggregate prior to the addition of emulsion, and water incorporated with the emulsion. The water incorporated with the emulsion contains soap or cationic surface active agents that decrease surface tension and improve the wetting characteristics of all water contained in the mix. It also allows microscopic asphalt droplets to maintain suspension in water.

The distribution of the residual asphalt in the paving mixture depends to a considerable extent on the type of emulsion. With solventless slow-setting emulsion, regardless of whether it is cationic or anionic, it may be expected that asphalt would be distributed in globules rather than the continuous waterproofing asphalt films. Such globules, initially attached to finer aggregate particles during the mixing process, are distributed throughout the mass of the mixture. They plug up the capillary openings and voids between large particles, and thereby waterproof the mix.

1.1.1 Dense Graded Mixes

The setting or breaking of emulsions is defined as the separation of asphalt and water, and can be observed in the field by a marked color change from brown to black (13). The release of straight water can often be observed. With anionic emulsions, it is believed, this occurs only by the evaporation of water. With cationics, evaporation speeds up breaking, but electrochemical action also occurs because of surface charges or attraction of the positively charged asphalt particle to the negatively charged aggregate surfaces, resulting in the deposition of asphalt on the aggregate.

Mix temperature is dependent on air temperature, since no heat is used in mixing. Temperature affects the breaking time, for it affects both evaporation and the speed of the electrochemical reaction. Evaporation also depends on humidity and wind velocity.

It is recommended that compaction should start when total fluid content is optimal, as determined by compaction tests. No mention is made of the degree of breaking of the emulsion required. Fortunately, breaking and optimum moisture occur at about the same time, and it is suggested that breaking is the best single guide or clue to when to start compaction (13).

One of the advantages often cited for using emulsion instead of cutbacks is its tolerance of wet aggregates. However, once the emulsion is mixed the requirement for curing before compaction is the same for both, and the time factors are also similar.

1.2 Mix-Design Requirements

A review of the literature indicates that most agencies and laboratories use conventional hot-mixed design procedures with minor modifications. The Hveem method is used by most highway departments in the Western United States, whereas the Marshall method is more popular in the remaining states, in federal agencies, and in foreign countries (13). The Marshall method is applicable to coarse mixture for low traffic volume pavements containing emulsion and mineral aggregates with maximum sizes of 1 inch or less.

Water in the mixture is the major cause of mix design problems. Because of the high moisture content at the time of compaction, it is impossible to reduce air voids in the total mix to a normal level. Hence, the major disagreement between laboratories is in the amount and method of curing. However, any design procedure utilized for emulsified asphalt mixtures (EAM) must determine the following (5):

1. the suitability of aggregates and emulsified asphalt,
2. the compatibility of emulsified asphalt and aggregate,
3. the optimal moisture content for compaction,
4. the optimal residual asphalt content, and
5. the adequacy of structural and durability properties.

In this study, however, consideration was taken with respect to all of the above requirements except the optimal residual asphalt content. Instead, variation of the amount of mineral filler in the mix and curing time were considered and analyzed rather than determining the optimal residual asphalt content for a job mix.

1.3 Objective and Scope of Study

This study was initiated to examine the behavior of cold mixes made with emulsified asphalt and used as surface course on low-volume roads.

The effect of the following two items on the integrity of the mix were evaluated:

1. Amount of mineral fillers (aggregates passing No. 200 (75 mm) sieve) and its contribution to the stability of the mix.
2. Temperature and curing time.

The method utilized in this study is primarily based on the Marshall mix-design method with minor modifications. An overview of the study is shown in Table 1.

Table 1

Plan of Study

Curing Time Condition	1 day in oven at 100^{O}F					2 days in oven at 100^{O}F				
% Residual Asphalt	3	4	5	6	7	3	4	5	6	7
% Fines										
4	X X	X X	X X	X X	X X	X' X'	X' X'	X' X'	X' X'	X' X'
7	X X	X X	X X	X X	X X	X' X'	X' X'	X' X'	X' X'	X' X'
10	X X	X X	X X	X X	X X	X' X'	X' X'	X' X'	X' X'	X' X'

NOTE:

1. Two observations of each treatment
2. Total number of treatments (n) = 60
3. X and X' can be any of the following:
   a. stability
   b. flow
   c. maximum total voids (MTV)
   d. dry bulk specific gravity (DBSG)
   e. moisture content (MC)

CHAPTER 2

PREPARATION OF MATERIALS NEEDED TO CONDUCT THE LABORATORY EXPERIMENTS

Unlike hot mixes which primarily consist of aggregate and a binder (asphalt cement-AC-usually), cold mixes contain three major ingredients: aggregate, a binder, and water. The water is added to the aggregate prior to introducing the emulsion to aid in proper coating of the aggregate (details in Chapter 4). Yet, characteristics of both aggregate and the emulsion are equally important to a good, stable, flexible mix. A wide range of materials are suitable for use with emulsified asphalt. Therefore, for any combination of aggregate and emulsion utilized in a cold mix, a judicious selection shall be made based on the chemistry of both the aggregate and the emulsion and their behavior in the mix. However, in this study, the emulsion and aggregate types selected were cationic slow setting-type 1 (CSS-1) emulsion, this emulsion was chosen because of its potential success in cold regions as claimed by its manufacturer. Quartzite aggregate was also used. Both materials are discussed in more detail in the subsequent paragraphs.

2.1 Asphalt Emulsion

All asphalts used in the United States are products of crude petroleum. Asphalt is produced in a variety of types and grades ranging from hard and brittle solids to almost water-thin liquids. For all asphalt products, asphalt cement is the base material. It can be liquified by heating, adding a solvent, or by emulsifying it before used in construction. When a petroleum solvent such as naphtha or kerosene is added to the asphalt cement to make it fluid, the final product is called a cutback. Cutbacks are classified according to their curing ability. The major classifications of cutbacks are rapid curing (RC), medium curing (MC), and slow curing (SC). On the other hand, when asphalt cement is broken into minute particles and dispersed in water with the aid of an emulsifying agent, it becomes an asphalt emulsion. The tiny droplets of asphalt remain uniformly in suspension until the emulsion is used for its intended purpose. An electrochemical action is what keeps the particles suspended during the liquid phase. Figure 1 shows the relative size and distribution of asphalt particles in an emulsion (2). When either cutbacks or emulsions are used in the field, the liquifying agent evaporates. In the case of emulsions, the remaining chemicals combine with the base asphalt to enhance the emulsion's properties. Then it will perform its functions of cementing and waterproofing.

2.1.1 Uses of Asphalt Emulsions

The use of asphalt emulsions for road construction and maintenance is not new. Emulsions were first developed in the early 1900's. It was not until the 1920's, however, that emulsions, as

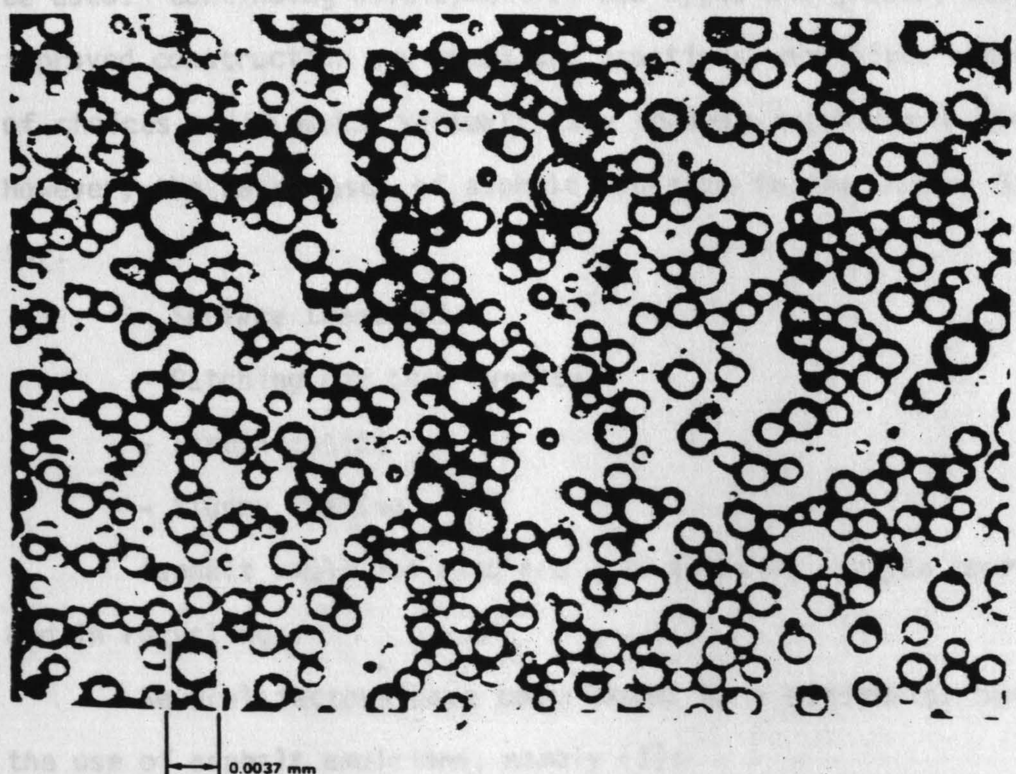

Figure 1. Relative sizes and distribution of asphalt particles in an emulsion.

(Courtesy Chevron U.S.A. Inc.)

known today, came into being. Their early use was confined largely to spray applications and use as a dust palliative. The growth in the use of asphalt emulsions was relatively slow. It was limited by the types available and a lack of knowledge as to how the emulsions should be used. Continuing development of new types and grades, coupled with improved construction equipment and practices, now gives a broad range of choices, with which virtually any roadway requirement can be met. However, the major uses of asphalt emulsion in the United States are for:

- Surface treatment
- Patching and thin overlays
- Stabilization
- Slurry sealing

Asphalt emulsions also are used in base, surface course mixes, and in recycling.

Several factors have contributed to a nationwide interest in the use of asphalt emulsions, namely (1):

- The energy crisis of the early 1970's that prompted conservation measures by the Federal Energy Administration. Asphalt emulsion does not require a petroleum solvent to make it liquid. Also, it can be used (in most cases) without additional heat. Both of these contribute to energy savings.

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- The ability of certain types of asphalt emulsion to coat damp aggregate surfaces, which is another energy saving feature.
- Availability of a variety of emulsion types, coupled with improved laboratory procedures, to satisfy design and construction requirements.
- Potential cost savings by the use of less fuel.

The two major environmental factors -- energy conservation and atmospheric pollution -- were mainly what caused an interest in the use of asphalt emulsions.

2.1.2 Composition of Asphalt Emulsions

An asphalt emulsion consists of three basic ingredients: asphalt, water, and an emulsifying agent. On some occasions the emulsifying agent may contain a stabilizer.

It is well known that water and asphalt will not mix, except under carefully controlled conditions using highly specialized equipment and chemical additives. One of the most economical and ample materials added as an emulsifying agent is soap. The soap particles surround the globules of asphalt, break the surface tension that holds them, and allow them to disperse in water. That is basically how the reaction occurs, and the object is to make a dispersion of the asphalt cement in water stable enough for pumping, prolonged storage, and mixing. Furthermore, the emulsion should break down quickly after contact with aggregate in a mixer or after spraying on the road bed. Upon curing, the residual asphalt retains all of the adhesion, durability, and water-resistance of the asphalt cement from which it was produced. However, the emulsion used in this particular study, as mentioned earlier, is cationic slow setting-type 1 (CSS-1). It is produced at Koch Asphalt Company, St. Paul, Minnesota, and its composition is as shown in Table 2.

2.1.3 Classification

Asphalt emulsions are divided into three categories: anionic, cationic, and nonionic. In practice, the first two types are ordinarily used in roadway construction and maintenance. Nonionics, however, may be more widely used as technology advances (2). The anionic and cationic classes refer to the electrical charges surrounding the asphalt particles. This identification system stems from one of the basic laws of electricity-like charges repel one another and unlike charges attract. So if a current is passed through an emulsion containing negatively charged particles of asphalt, the particles will migrate to the anode, and the emulsion is considered anionic. Conversely, positively charged asphalt particles will travel to the cathode, and the emulsion is known then as cationic. If the asphalt particles do not move to either pole, then they are neutral, and the emulsion is classified noionic.

Table 2

Composition of CSS-1 Type Emulsion

Ingredient	% By Weight
Petroleum Asphalt	57-65
Additives	< 4
Water	Balance

Emulsions are further classified on the basis of how quickly the asphalt will coalesce; i.e., revert to asphalt cement. Terms such as RS, MS, and SS have been adopted to simplify and standardize this classification. The terms are relative only, and mean rapid-setting, medium setting, and slow-setting. The tendency to coalesce is closely related to the mixing of an emulsion. An RS emulsion has little or no ability to mix with an aggregate; an MS emulsion is expected to mix with coarse but not fine aggregate; and finally, an SS emulsion is designed to mix with fine aggregate (2).

Furthermore, the emulsions are subdivided by a series of numbers related to viscosity of the emulsions and hardness of the base asphalt cements. The designated letter "C" in front of the emulsion type denotes cationic and its absence denotes anionic or nonionic. For example, RS-1 is anionic or nonionic and CRS-1 is cationic emulsion. The classifications of asphalt emulsions are shown in Table 3.

2.1.4 Specifications

Standard specifications for the grades of emulsions have been developed by ASTM and the American Association of State Highway and Transportation Officials (AASHTO). Those specifications depend mainly on the type, electrical charges, and coallision speed of the emulsion, and are shown in Table 3. The letter "h" that follows certain grades simply means that a harder base asphalt cement is used. The "HF" preceding some of the MS grades indicates high-float, as measured by the Float Test (ASTM D139 or AASHTO T50).

Table 3

Classifications of Asphalt Emulsions

Emulsified Asphalt	Cationic Emulsified Asphalt
RS-1	CRS-1
RS-2	CRS-2
MS-1	-----
MS-2	CMS-2
MS-2h	CMS-2h
HFMS-1	-----
HFMS-2	-----
HFMS-2h	-----
HFMS-2s	-----
SS-1	CSS-1*
SS-1h	Css-1h

*Used in this study.

The emulsion used for this study falls in the cationic emulsions category. It should be noted that the emulsion used was CSS-1 and not the high-float type. Physical characteristics of the CSS-1 type emulsion are shown in Table 4 and are presented as provided by the manufacturer.

2.2 Aggregate

In cold mixes, as well as in all asphalt mixes, the aggregates normally constitute 90 percent to 95 percent by weight of the total mix. This points out the significance of selecting the right type of aggregate to be used in the mix (12).

Aggregate materials often are identified in broader terms as rock, sand, and dust. These terms usually are applied to the stockpiled materials supplied to the job site. The following definitions appear to have the greatest usage (16):

Rock - Materials that are predominantly coarse aggregate (all material retained on the No. 8 sieve).

Sand - Materials that are predominantly fine aggregate (all material passing the No. 8 sieve).

Dust - Materials that are predominantly mineral filler (finely divided material, most of which will pass the No. 200 sieve).

Table 4

CSS-1 Emulsion Physical Data

Property	Description
Physical Description	Chocolate Brown Liquid, sweetish odor
Boiling Point	$212^{O}F$
Vapor Pressure	23.7 mm of Hg @ $77^{O}F$
Vapor Density	0.62
Solubility in Water	Soluble
Specific Gravity	1.02
% Volatile by Volume	32-42
Evaporation Rate	NO DATA

2.2.1 Quartzite

Geologically, quartzite is a metamorphic rock originating from sandstone. As the type of metamorphism varies, the color of quartzite changes from white and/or stained red when pure, to yellow or other colors, depending on the impurities in it. The major mineral constituent of quartzite is silica, and its amount could vary depending on its source, as shown in Table 5 (11). In this study, Dell Rapids quartzite is used. Silica constitutes about 96 percent of its composition. Figure 2 shows Dell Rapids quartzite; and its stained red color denotes its purity.

It is of great importance to note that quartzite, as it exists in nature, carries negative charges, and since a cationic emulsion which carries positive charges is considered in this study, these two materials will form a strong bond when mixed together. For that reason, and since quartzite is a hard material, having a high hardness number (11), quartzite was selected as the aggregate with which to experiment.

2.2.2 Gradation

One of the common mixes used in the State of South Dakota is called Class G-type 1. A gradation was selected to satisfy this mix, in an attempt to come up with a dense graded mix to be used as a surface course for a low volume road. The gradation selected, along with the specific amount of aggregate (in grams) for each fraction size, is shown in Table 6.

Table 5

Chemical Composition of Quartzite

Content		In Percent	
Site	Dell Rapids	Spencer	Sioux Falls
<u>Element</u>			
Silica (S_1+O_2)	96.26	99.14	97.58
Iron Oxide (Fe_2O_3)	1.74	0.50	1.20
Alumina (Al_2O_3)	0.67	0.28	0.31
Magnesia (MgO)	0.09	trace	0.10
Potassium (K_2O)	trace	N/A	0.14
Calcium Oxide (CaO)	0.20	trace	0.14
Loss on ignition	0.16	N/A	0.03

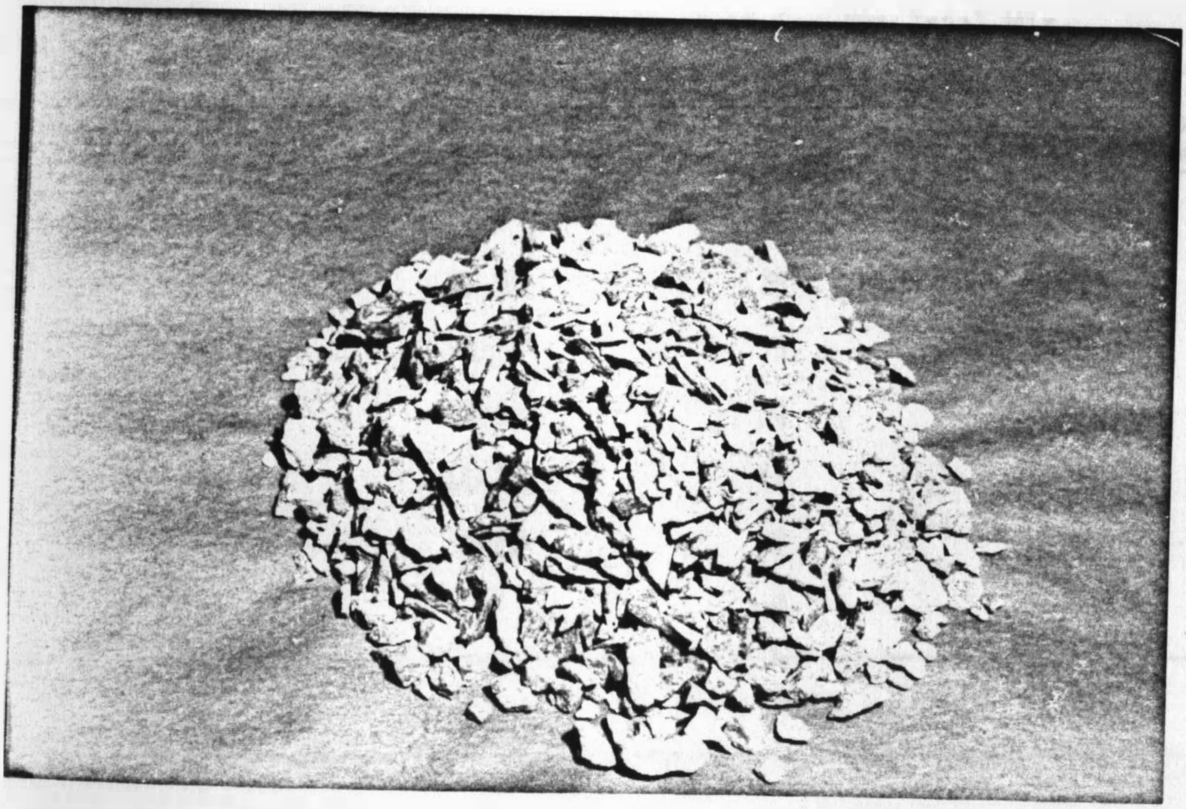

Figure 2. Dell Rapids quartzite.

Table 6

Aggregate Gradation Used for the Trial Mix

Sieve Size	% Passing South Dakota Class G-Type 1	% Passing Selected Gradation	Amount Of Aggregate For One Specimen (gms)
5/8"	100	100	0
3/8"	70-90	75	300
#4	52-70	55	240
#10	32-52	35	240
#40	15-32	17	216
#200	4-10	6	132
PAN		0	72
		TOTAL	1200

In this study, the amount of mineral filler (aggregate passing the No. 200 sieve) was varied. This variation actually changed the amount of aggregate retained on the No. 200 sieve and the pan. The amount of mineral fines were 4 percent, 7 percent, and 10 percent of the total aggregate weight.

CHAPTER 3

LABORATORY TESTING PROCEDURE AND RESULTS

Due to the many factors affecting cold mixes using emulsified asphalt, a pre-determined design does not apply to such mixes. The design factors for the main experiment must be obtained by conducting various preliminary laboratory tests. The main experiment in this study utilizes a modified Marshall mix design concept, as mentioned earlier.

This part of the study concentrates on all necessary calculations and on the preliminary tests conducted to obtain the main mix design factors. The following is a list of the tests and calculations performed:

1. Calculations of the trial residual asphalt content.
2. The coating test in which a pre-mix water content was determined.
3. An optimum water content at compaction test.
4. An experiment to determine the testing temperature.
5. Calculations for adjusting the amount of aggregate in the mix.

In addition, this part of the study examines the main experiment performed in the laboratory to determine the major properties of cold mixes, which will be analyzed and studied in a later chapter.

3.1 Trial Residual Asphalt Content

The method for determining the trial residual asphalt content consists of two major calculations.

First the emulsified asphalt content, which is calculated as follows, which is recommended by the Asphalt Emulsion Manufacturers Association (AEMA) (2),

$$P = 0.05\ A + 0.1\ B + 0.5\ C$$

where,

P = percent by weight of emulsified asphalt, based on weight of graded mineral aggregate.

A = percent of mineral aggregate retained on 2.36 mm (No. 8) sieve.

B = percent of mineral aggregate passing 2.36 μm (No. 8) sieve and retained on 75 μm (No. 200) sieve.

C = percent of mineral aggregate passing 75 μm (No. 200) sieve.

P, A, B, and C are expressed as whole number.

Second, the residual asphalt content, which is calculated as follows:

$$\text{Residual Asphalt Content} = P * d$$

where,

P = percent by weight of emulsified asphalt.

d = percent of residual asphalt in emulsion.

3.1.1 Sample Calculations

A = Retained on 2.36 mm (No. 8) sieve = 54 percent

B = Passing 2.36 mm (No. 8) sieve and retained on 75 μm (No. 200) sieve = 40 percent

C = Passing 75 μm (No. 200) sieve = 6.0 percent

d = Percent residual asphalt in emulsion (CSS-1) = 65.0 percent

Then,

P = 0.05 (54.0) + 0.1 (40.0) + 0.5 (6.0) = 9.7 percent and the trial residual asphalt content = 9.7 * 0.65 = 6.3 percent. 6.0 percent is used.

A more accurate method, performed in the laboratory, can be utilized to determine the trial residual asphalt content. It is known as the Centrifuge Kerosene Equivalent (C.K.E.) method (7). With a calculated surface area and the factors obtained by the C.K.E. test for a particular aggregate or blend of aggregates, the approximate asphalt content is determined using a series of charts.

Yet, if the C.K.E. test equipment is not available (which is the case in this study), the formula presented above can be used to provide an approximation of the trial residual asphalt content (2).

3.2 Preliminary Experimental Work

3.2.1 Coating

Selection of emulsified asphalt type and grade for use on a particular project is based in part on the ability of the emulsion to adequately coat the job aggregate. Other factors which affect this selection are:

(1) Aggregate type, such as natural aggregate, quartzite, etc.

(2) Aggregate gradation and characteristics of the mineral filler.

(3) Anticipated water content of the aggregate.

(4) Availability of water at the construction site.

For a given aggregate, more than one type of emulsion is often acceptable, and the selection should be based on mixture properties determined by comparative mixture design. Such properties that influence the section are: percent coating of the aggregate, stability of the mixture, workability of the mixture, and so on. Additional factors that cannot be evaluated at the time of mix design, but which should be accounted for at the time of construction are (1):

(1) Anticipated weather.

(2) Type of mixing process.

(3) Construction equipment selected and field procedures used.

3.2.1.1 Coating Test

Preliminary evaluation of each emulsified asphalt selected for mixture design is accomplished through a coating test. The trial residual asphalt content as determined in paragraph (3.1) is combined with the job aggregate, and coating is visually estimated as a percentage of the total area. An emulsified asphalt's ability to coat an aggregate is usually sensitive to the premix water content of the aggregate. This is especially true for aggregates containing a high percentage of material passing a 75 μm (No. 200) sieve, where insufficient pre-mixing water results in balling of the asphalt with the mineral fillers and insufficient coating. For this reason, the coating test is performed at varying aggregate water contents. Emulsified asphalts which do not pass the coating test are not considered further. Detailed procedures for the coating test are listed below.

3.2.1.2 Equipment

(a) Balance 5,000 gms. minimum capacity and accurate to within ± 0.5 gms.

(b) Laboratory mixing equipment, preferably mechanized and capable of producing intimate mixtures of the job aggregate, water and emulsified asphalt. Hand mixing, if used, must be sufficiently thorough to uniformly disperse the water and emulsion throughout the aggregate.

(c) An oven that can be controlled at $100^{\circ} \pm 5^{\circ}C$ ($230^{\circ} \pm 9^{\circ}F$).

(d) Metal pans, approximately 200 x 355 x 50 mm (8 x 14 x 2 in.).

(e) Supply of metal kitchen mixing spoons (approximately 250 mm (10 in.)).

3.2.1.3 Procedure

This procedure is in accordance with the method outlined in the Asphalt Emulsion Manual (1), and is as follows:

(a) A representative sample of the emulsion considered for the project (CSS-1) was obtained.

(b) A representative sample of the job aggregate was obtained.

(c) The aggregate was oven dried until it was easily separated into the specified sieve sizes.

(d) The moisture content of the aggregate was determined according to ASTM Test Method D2216, "Laboratory Determination of Moisture Content of Soil," and results were recorded.

(e) Four separate batches of the dried aggregate were prepared for trail mixes. Each batch mass was approximately 1200 g (oven dry basis). These batches were prepared by reblending exact fractions of materials retained on the sieves specified for this project.

(f) One at a time, the batches were placed in the mixing bowl of the mechanical mixer. An "X" percent of water was incorporated by dry weight of aggregate in excess of the air dried water content (if any). Water was added in a thin stream and the aggregate was mixed until the water was thoroughly dispersed. (Sixty seconds of mixing time was sufficient to provide thorough dispersion of the water.) The initial "X" percentage water was selected according to the following criteria:

- slow setting (SS and CSS) asphalt emulsions. These often require a higher water content to produce satisfactory mixes; the coating test should start at about 3 percent added water (2).

(g) The amount of emulsified asphalt (percent by weight of dry aggregate) as determined in paragraph (3.1) was added. The emulsion was added in a thin stream to minimize the tendency of the asphalt to ball up with the mineral filler. A 30 seconds mixing time was satisfactory.

(h) The free water content of the aggregate at mixing was calculated by combining the moisture content of the aggregate with the percentage of water added.

<u>EXAMPLE</u>

Water content of air-dried aggregate = 0.75 percent.

Percentage of water added prior to addition of emulsified asphalt = 3.5 percent.

Therefore, total premix water before mixing with emulsified asphalt = 4.25 percent.

(i) The mixture was allowed to air dry with the aid of an electric fan. At this time the other batches were prepared in the same manner. Mixes that became soupy were considered unacceptable.

(j) The appearance of the surface dry mixture was rated by visually estimating the total aggregate surface area coated with asphalt.

3.2.1.4 Results

Coating tests were conducted using the trial residual asphalt content (5.0 percent) and a range of mixing water contents (3-6 percent). By visual observation, results showed the following:

Mixing Water Content	Estimated Percent Coating
3	80
4	90
5	100
6	Soupy Conditions

At 6 percent mixing water content, the mix showed soupy conditions. Thus, 6 percent or more shall not be considered for this mix. Moreover, a mixing water up to 5 percent for this specific emulsion (CSS-1) and aggregate (quartzite) will provide adequate coating. In this particular mixture and throughout the rest of this study, a 5 percent mixing water content will be used.

3.2.2 Optimum Water Content at Compaction

Mixture properties are closely related to the density of the compacted specimens. Thus, it is necessary to optimize the water content at compaction to maximize the desired mixture properties. This must be done for each combination of emulsion type, emulsion grade, and aggregate type considered for each project.

3.2.2.1 Equipment

The following equipment was used for the preparation of test specimens:

(1) Scoop, for batching aggregate.

(2) Thermometer, $10^{o}C$ ($50^{o}F$) to $65.5^{o}C$ ($150^{o}F$).

(3) Balance, 2 kg capacity, sensitive to $\pm$ 0.1 g.

(4) Mixing spoon, large.

(5) Spatulas, small and large.

(6) Mechanical mixer, capacity to handle 2500 g.

(7) Mechanical compaction machine.

(8) Compaction molds consisting of base plates, forming molds, and collar extensions. The forming mold has an inside diameter of 101.6 mm (4 in.) and height of approximately 76 mm (3 in.); the base plate and collar extension are designed to be interchangeable with either end of the forming mold.

(9) Extrusion jack for extruding compacted specimens from mold.

(10) Gloves, welders, for handling hot equipment and for avoiding direct contact of emulsions with skin.

(11) Paper tape for identifying test specimens.

(12) Pans, metal, for batching aggregates.

(13) Oven, forced draft, capable of maintaining a temperature of 110 $\pm$ 2.8°C (230 $\pm$ 2.8°F) for determining moisture content.

3.2.2.2 Preparation of Test Specimens

(1) Number of specimens. Two specimens for each water content at compaction were prepared.

(2) Preparation of molds and hammer. The specimen mold assemblies and the face of the compaction hammer were thoroughly cleaned. A piece of filter paper toweling cut to size was placed in the bottom of the mold before placing the mixture in it.

(3) Preparation of aggregate. Each size fraction of the aggregate was recombined to produce a total aggregate weight of 2400 g (2.4 kg). The temperature of the aggregate was checked and determined to be within 72 $\pm$ 3°F (22.2 $\pm$ 1.7°C) prior to mixing.

(4) Calculations. Four calculations were made for each combination of aggregate and asphalt: weight of aggregate, weight of emulsion, weight of added

pre-mixing water, and weight of water need to be removed (by aeration before) compaction. The following formulas were used for the calculations:

(1) Weight of air-dried aggregated added =

$$(a/(100-b))*100 \qquad (4\text{-}A)$$

(2) Weight of emulsion =

$$(a*c)/d \qquad (4\text{-}B)$$

(3) Weight of pre-mixing water added =

$$a(f-b-(e*c/d))/100 \qquad (4\text{-}C)$$

(4) weight of water loss before compaction =

$$a((f-g)/100) \qquad (4\text{-}D)$$

where

a = weight of dry aggregate.

b = percent water content of air-dried aggregate.

c = desired residual asphalt content, percent by weight of dry aggregate.

d = percent residual asphalt in the emulsion.

e = percent water in emulsion = 100-d.

f = percent pre-mix water content at mixing (weight dry aggregate).

g = percent water content at compaction by weight of dry aggregate.

(5) Addition of pre-mixing water. After placing the aggregate in the mixing bowl, the amount of pre-mixing water, as determined earlier, was added in a thin stream. Care was taken to ensure that water temperature was in the range $72 \pm 3^{o}F$ ($22.2 \pm 1.7^{o}C$). The water was mixed with the aggregate in a mechanical mixer for 1.5 ± 0.5 minutes.

(6) Addition of emulsion. The amount of emulsion, as determined by the trial residual asphalt content, was added to the moistened aggregate in a thin stream as the material was mixing. Mixing time of 1 ± 0.5 minutes showed satisfactory dispersion.

(7) Aeration to reduce the water content of the mixture. Whenever the desired water content at compaction differed from the optimum mixing water content, it was necessary to aerate the material. All the material was removed from the mixing bowl and placed in an aeration pan. The mixture was distributed in the pan so that the depth did not exceed one inch. The weight of the mixture and pan was recorded, and the required weight loss to reach the desired compaction water content was calculated by Equation (4-D). The mixture was then left to dry with the aid of an electric fan. The mix was frequently stirred until the appropriate amount of water loss was reached.

(8) Compaction of specimens. The base plate, Marshall forming mold, and collar extension were assembled with the base plate, which was covered with a piece of filter paper cut to size. The mixture was placed in the mold assembly and spaded with a small spatula 15 times around the perimeter and 10 times over the interior. A second piece of filter paper cut to size was placed over the top of the mixture. The mold assembly was then placed on the compaction machine. Fifty blows were applied to each face of the mold. The filter paper, along with the collar extension and the base plate, were removed from the mold.

(9) Curing of specimens. Specimens were cured at 72 $\pm$ 3^{o}F (22.2 $\pm$ 1.7^{o}C) in the forming mold for a period of 24 hours. During curing, specimens were set on their edges to ensure equal ventilation on both sides.

(10) Testing for stability. Specimens were tested for Marshall stability as described in paragraph (3.3.3). A plot was then prepared showing the relationship between water content at compaction and stability. The optimum water content at compaction was determined as the peak of that curve (Figure 3).

3.2.2.3 Sample Calculations

a = mass of dried aggregate = 1200 g.

b = percent water content of dried aggregate = 0.0.

c = desired residual asphalt content = 5.0 percent.

d = percent residual asphalt in the emulsion = 65 percent as supplied by manufacturer.

e = percent water in the emulsion = 35 percent.

f = percent pre-mixing water content = 5.0 percent.

g = desired percent water content at compaction = 2 percent.

(1) weight of air dried aggregate added = a/(100-b)*100

= (1200/100-0)*100 = 1200 g.

(2) weight of emulsion = (a*c)/d = (1200*5)/65 = 92.3 g.

(3) weight of pre-mixing water added = a(f-b-(e*c/d))/100

= 1200(5-0-(35*5/65))/100

= 27.7 ≃ 28 g.

(4) weight of water loss for compaction = a(f-g)/100 = 1200(5-2/100)

= 36 g.

3.2.2.4 Results

Specimens were compacted at varying water contents, ranging from 2 to 6 percent (2 specimens at each water content). The specimens contained 5 percent residual asphalt and mixed at 5 percent pre-mixing water content, yet compacted at 2, 3, 4, 5, and 6 percent water. The mixture was allowed to aerate with the aid of an electric fan when the water content at compaction was less than the pre-mixing water content. More water was added when the water content at compaction exceeded the pre-mixing water content. Table 7 shows the amounts of water losses and additions.

After 24 hours of curing, the specimens were extruded and tested for Marshall stability at 72^{O}F (22.2^{O}C). Figure 3 and Table 8 show that optimum stability occurs at a water content of 5 percent. This is within the acceptable range of pre-mixing water contents, and is used in the main testing of specimens, see Section (3.3) of this chapter.

3.2.3 Determination of Testing Temperature

This test was conducted in an attempt to reach an acceptable temperature for which specimens are cured and tested. The importance of this test comes into picture at this level of testing since no need for oven temperatures was necessary for all the tests conducted so far. All the previous testing was performed under room-temperature conditions.

3.2.3.1 Testing

All specimens were prepared and tested in accordance with sections (3.2) and (3.3) of this chapter. Listed below are some hints concerning the nature of the test:

1. Five different temperatures were chosen, including room temperature (75^{O}F).

Table 7

Amounts of Water Loss for Compaction

Desired Water Content at Compaction (%)	Amount of Water Loss for Compaction (gms)
2	36
3	24
4	12
5	0
6	-12*

*(-12) means that 12 grams of water were added in excess of the required pre-mixing water amount.

Table 8

Determination of Optimum Water Content at Compaction

Specimen Identification*	Load Dial Reading	Stability (lbs)**	Correction Factor	Corrected Stability (lbs)
2 A	29	729.33	0.711	519
2 B	38	858.66	0.744	639
3 A	31	758.07	0.712	540
3 B	38	858.66	0.728	625
4 A	48	1002.36	0.744	746
4 B	52	1059.84	0.711	754
5 A	74	1375.98	0.744	1024
5 B	61	1189.17	0.743	884
6 A	57	1131.69	0.744	842
6 B	47	987.99	0.744	735

*The numerical value (i.e. 4-A) means 4% water content.

**Stability (lbs) = 312.6 + 14.37 (X), where X = Load Dial Reading

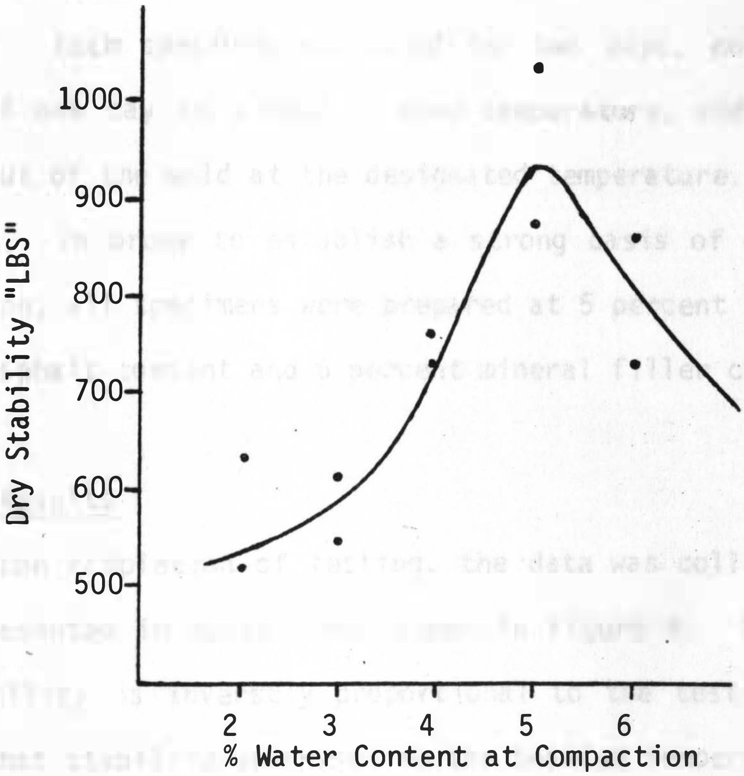

Figure 3. %W/C at compaction vs. dry stability.

2. Two specimens were prepared and tested at each temperature.

3. Each specimen was cured for two days, consisting of one day in a mold at room temperature, and one day out of the mold at the designated temperature.

4. In order to establish a strong basis of comparison, all specimens were prepared at 5 percent residual asphalt content and 6 percent mineral filler content.

3.2.3.2 Results

Upon completion of testing, the data was collected (see Table 9) and presented in curve form, shown in Figure 4. The figure shows that stability is inversely proportional to the testing temperature, meaning that stability decreases as the testing temperature increases. The largest apparent reduction in stability occurred when the temperature was raised from 75°F (room temperature) to 100°F. This reduction will act as a safety factor included in the design. Moreover, 100°F somewhat simulates the field conditions for a cold mix. Therefore, 100°F was chosen as the design testing temperature for the main test of this study.

3.2.4 Adjustment of Amount of Mixture

Generally it is desirable to prepare a single trial for the type of aggregate considered for the job prior to compacting the test

Table 9

Temperatures Tested

Temp. at at which Specimen is Tested (^{o}F)	Load Dial Reading (L.D.R.)	Stability (LBS.)	Correction Ratio	Corrected Stability (LBS.)
75 A	85	1534.05	0.98	1503.37
75 B	90	1605.90	0.98	1573.78
100 A	48	1002.36	0.96	962.27
100 B	51	1045.47	0.93	972.29
110 A	26	686.22	0.93	638.20
110 B	26	686.22	1.00	686.22
120 A	23	643.11	1.04	668.83
120 B	27	700.59	0.86	602.51
130 A	19	585.63	0.96	562.20
130 B	19	585.63	0.83	544.64

*Stability = 312.6 + 14.37 (L.D.R.).

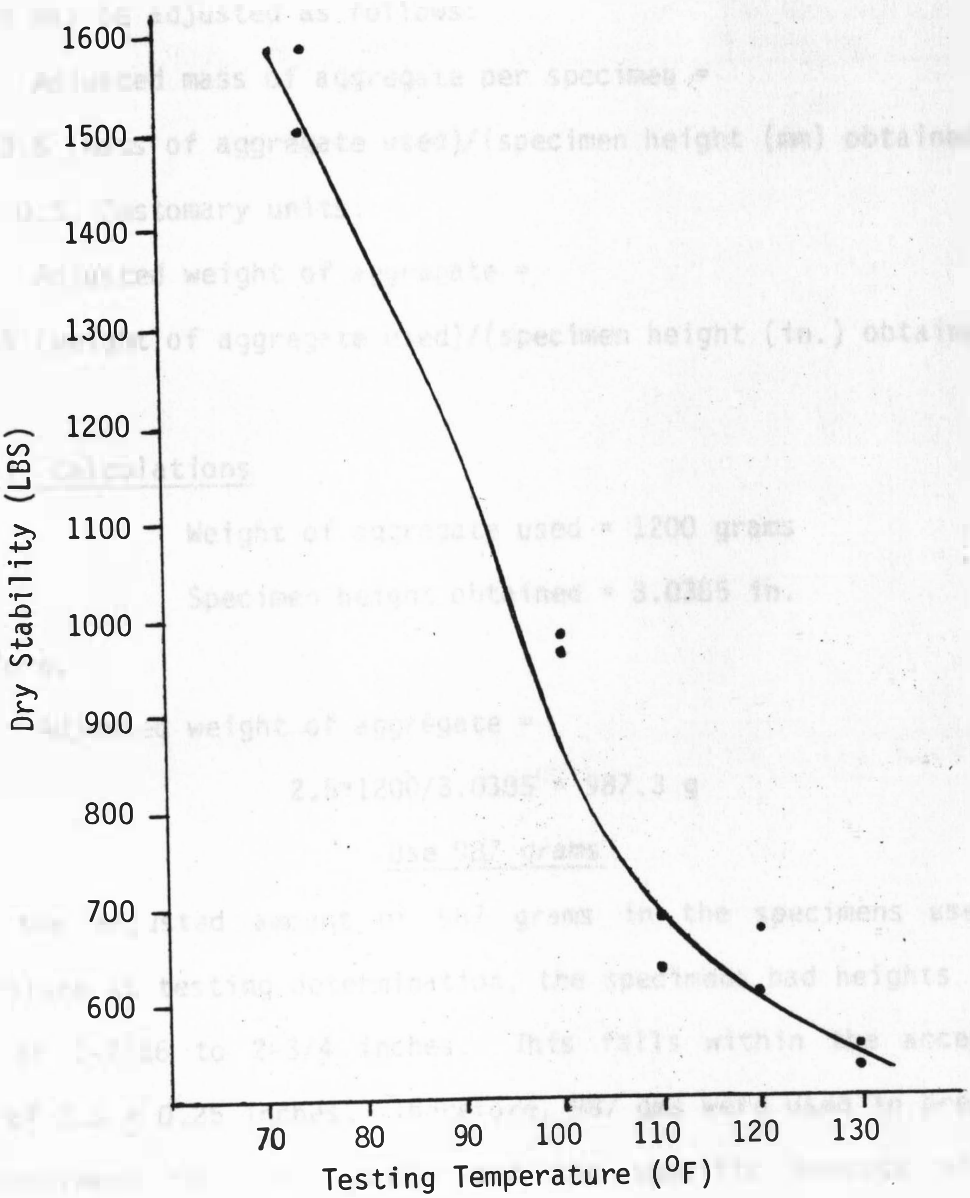

Figure 4. Testing temperature vs. dry stability.

specimens. Should the height of the extruded trial specimen fall beyond the limits of 63.5 ± 6 mm (2.5 ± 0.25 in.), the amount of mixture may be adjusted as follows:

Adjusted mass of aggregate per specimen =

63.5 (mass of aggregate used)/(specimen height (mm) obtained)

or for U.S. Customary units:

Adjusted weight of aggregate =

2.5 (weight of aggregate used)/(specimen height (in.) obtained)

3.2.4.1 Calculations

Weight of aggregate used = 1200 grams

Specimen height obtained = 3.0385 in.

Therefore,

Adjusted weight of aggregate =

2.5*1200/3.0385 = 987.3 g

Use 987 grams

Using the adjusted amount of 987 grams in the specimens used for temperature at testing determination, the specimens had heights in the range of 2-7/16 to 2-3/4 inches. This falls within the acceptable range of 2.5 ± 0.25 inches. Therefore, 987 gms were used in preparing all specimens for this study, and the specific amounts of each fraction size are shown in Table 10.

Table 10

Adjusted Amounts of Aggregate Used for the Trial Mix

Sieve Size	Adjusted Amounts for 1 Specimen (gms)	Selected Gradation % Passing
5/8"	0	100
3/8"	247	75
#4	197	55
#10	197	35
#40	178	17
#200	109	6
PAN	59	0
TOTAL	987	

3.3 The Main Experimental Work

The objective of this test is to determine the major properties of emulsified asphalt-aggregate cold mixes used as a wearing course for low volume roads; these properties are discussed in Chapter 4 of this study. Test mixtures are prepared in 1 percent increments of residual asphalt content with two increments on either side of the trial asphalt content determined in paragraph (3.1) of this chapter, and 3 percent increments of mineral fillers in compliance with South Dakota Department of Transportation Standard specifications for roads and bridges (3).

3.3.1 Equipment

The equipment required for preparation of specimens are the same ones listed under Equipment, 3.2.1.2 of this chapter. The equipment required for testing the specimens are listed below:

(1) Marshall Testing Machine. A compression testing device. It is designed to apply loads on test specimens through semicircular testing heads at a constant rate of strain of (50.8 mm) 2 inches per minute. It is equipped with a calibrated proving ring for determining the applied testing load, a Marshall stability testing head for use in testing the specimen, and a Marshall flow meter for determining the amount of strain at the maximum load of the test.

(2) Balance, 1500 gm capacity, equipped for density determination.

(3) Towels, cloth for drying samples during bulk density determination.

3.3.2 Preparation of Specimens

The procedure for preparation of specimens listed in paragraph (3.2.2.2) of this chapter is used. Additional instructions and clarifications presented below correspond to the appropriate paragraphs of that section.

(1) Number of specimens. A total of sixty specimens were prepared. Four identical specimens were prepared at each combination of mineral filler and residual asphalt contents. Thirty specimens were tested at one day curing in the oven, and the other thirty were tested at two days curing in the oven.

(2) Preparation of molds and hammer. No change.

(3) Preparation of aggregate. A total aggregate mass of 987 grams for each specimen batch was used.

(4) Calculations. No change.

(5) Addition of pre-mixing water. Table 11 shows the amounts of water added.

(6) Addition of emulsion. Table 11 shows the amounts of emulsion added.

Table 11

Amounts of Pre-Mixing Water and Emulsion per Specimen

Residual Asphalt Content (%)	Mass of Pre-Mix Water Added (gms)	Amount of Emulsion (gms)
3.0	33.5	46.0
4.0	28.0	61.0
5.0	23.0	76.0
6.0	17.5	91.0
7.0	12.5	106.0

(7) Aeration to reduce the water content of the mixture. It was not necessary to aerate since the pre-mixing water was determined to be the same necessary for optimum water content at compaction.

(8) Compaction of specimens. No change.

(9) Curing of specimens. All specimens were cured for one day in a mold at room temperature. They were extruded, all specimens were cured for another day in an oven. Half were tested after 24 hours and the other half were cured for additional 24 hours at $100^{o}F$ ($38^{o}C$). See Figure 5.

3.3.3 Procedure of Testing for Marshall Stability and Flow

Before testing the specimens for Marshall stability and flow, the bulk specific gravity of each specimen was determined according to methods ASTM D2726, "Bulk Specific Gravity and Density of Compacted Bituminous Mixtures Using Saturated Surface-Dry Specimens" and ASTM D118, "Bulk Specific Gravity and Density of Compacted Bituminous Mixtures Using Paraffin-Coated Specimens." Note: Gloss Latex Paint was used instead of paraffin in method ASTM D1188, see Figure 6. It was found by experiments that paraffin when used to coat a cold mix specimen tends to break up the bonding and cause a total failure of that mix specimen. That may be due to the temperature of the melted paraffin ($300^{o}F$) when used. Other materials such as regular paints

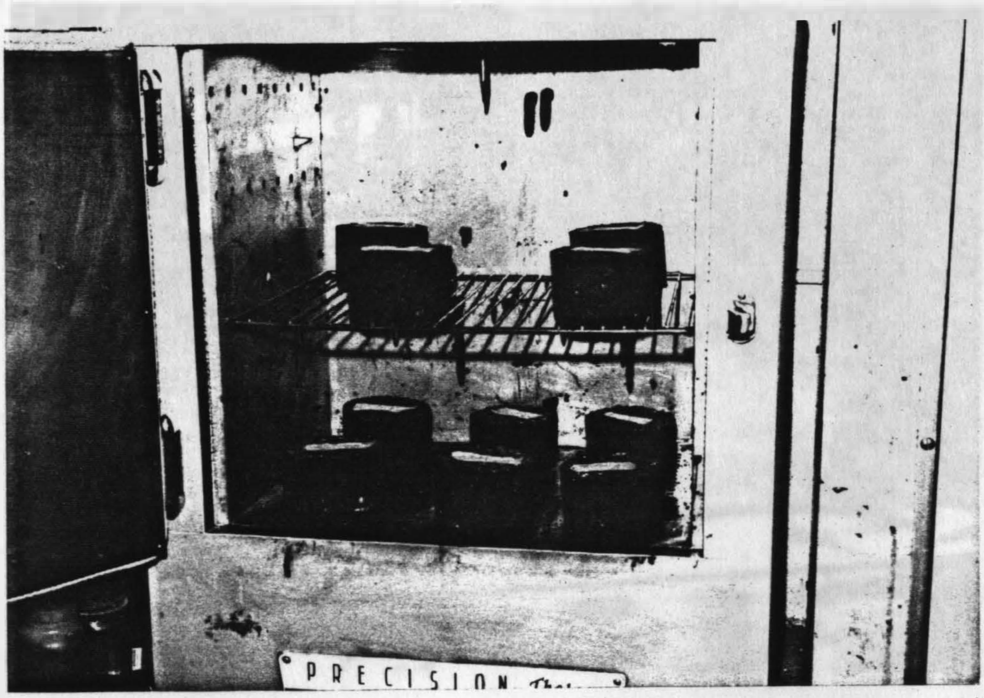

Figure 5. Curing of specimens in oven.

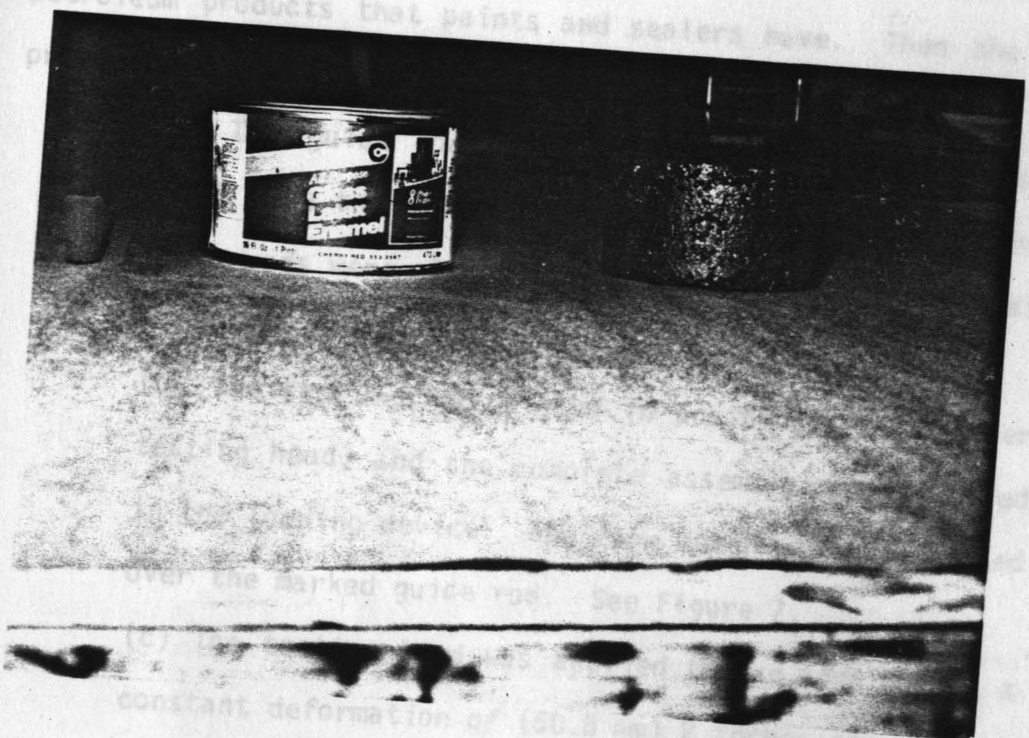

Figure 6. Gloss Latex enamel used to coat the specimens.

and sealers had the same effect on the cold mix specimen due to the petroleum products that paints and sealers have. Then the following procedure was followed:

(a) The guide rods and inside surfaces of the test heads were thoroughly cleaned prior to the test. The guide rods were also lubricated so that the upper test head slid freely over them.

(b) The specimen was placed in position on the lower testing head, and the complete assembly was centered in the loading device. The flow meter was then placed over the marked guide rod. See Figure 7.

(c) The testing load was applied to the specimen at a constant deformation of (50.8 mm) 2 inches per minute, until failure was obtained. The total number of pounds required to produce failure of the specimen was noted.

(d) The flow meter was held firmly in position during the stability test and removed the instant the maximum load was reached. Flow values were recorded in 0.01 inch units.

(e) The failed specimens were placed in pans, broken up, and put in an oven at ($200 \pm 10^{o}F$). The specimens were removed after 24 hours, reweighed, and the weights were recorded. See Figure 8.

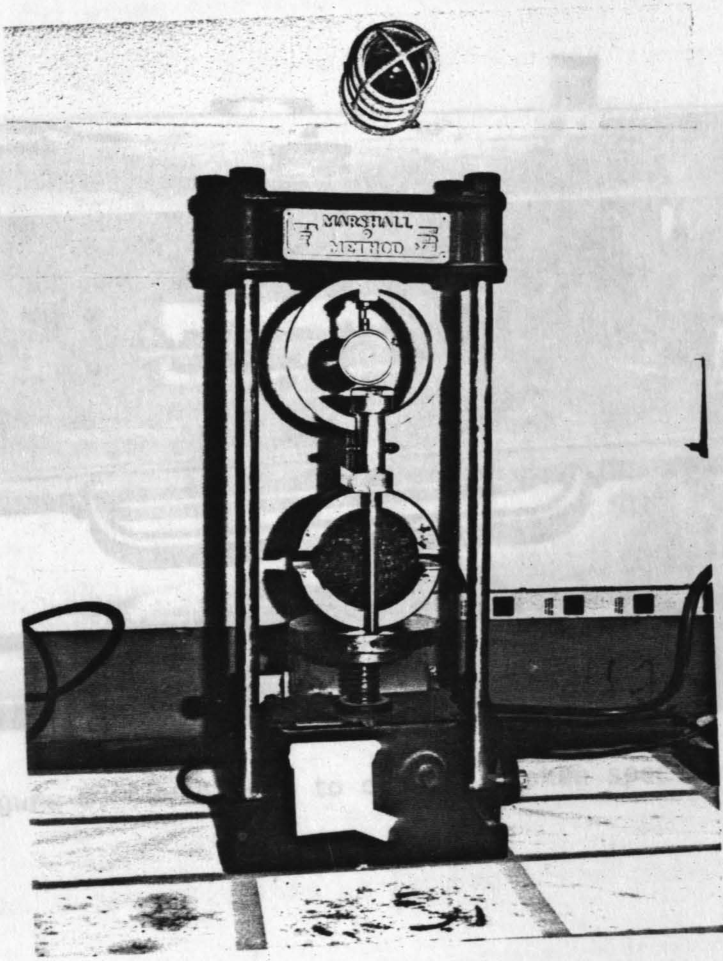

Figure 7. Marshall stability testing machine.

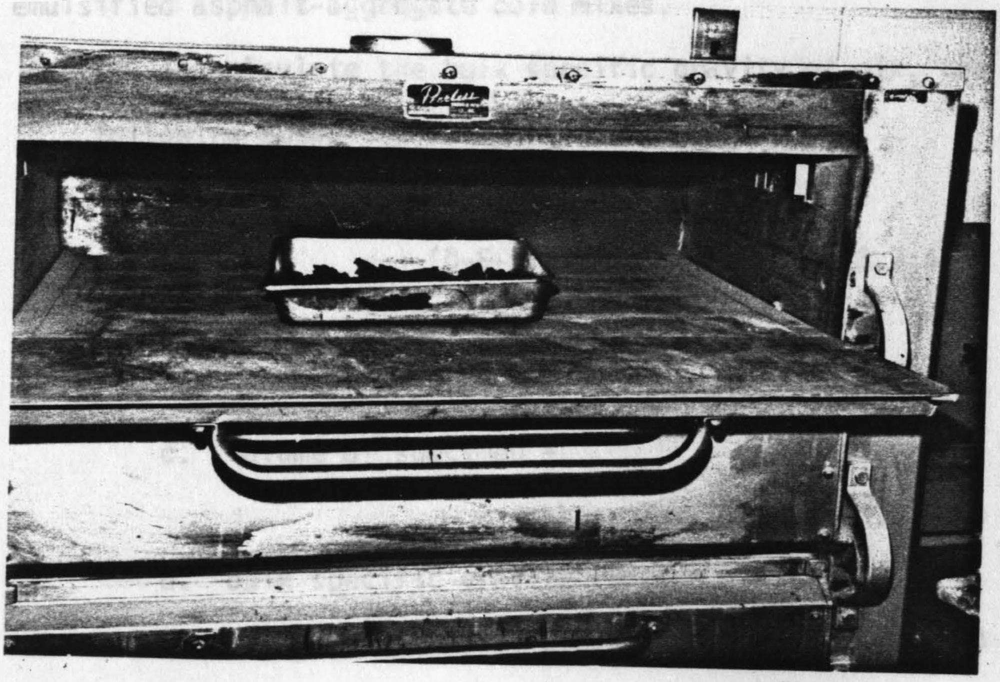

Figure 8. Oven used to dry the broken specimens.

3.3.4 Mix Design Calculations

The following equations were used to determine the properties of emulsified asphalt-aggregate cold mixes.

1. To calculate the bulk specific gravity of mix, the following steps are followed,

   a. volume of specimen + paint =

   $$(D-E-(F-d))/\gamma\omega \quad \text{.........(3.3.4-A)}$$

   b. volume of paint =

   $$(D-G)/(sp.gr._{(paint)} x\gamma\omega) \quad \text{......(3.3.4-B)}$$

   c. volume of specimen =

   $$a-b \quad \text{................(3.3.4-C)}$$

   d. bulk specific gravity (BSG) =

   $$G/\text{vol. of spec} \quad \text{..........(3.3.4-D)}$$

2. Dry BSG =

   $$BSG/(1+(K/100)) \quad \text{.........(3.3.4-E)}$$

3. Moisture content at testing (K) =

   $$((H-I)-(F-D))/I \times 1/1-(A/100) \quad \text{...(3.3.4-F)}$$

   Note - if F<D the term (F-D) is omitted from the equation

4. Maximum Total Voids (MTV) =

   $$((A/100)+1+(K/100)/BSG)-1/C-(A/100)/B))/((A/100)+1+(K/100)/BSG)x100 \quad \text{.......(3.3.4-G)}$$

where

A = residual asphalt in mix

B = asphalt specific gravity

C = mixed aggregate bulk specific gravity

D = weight of specimen + paint in air

E = weight of specimen + paint in water

F = weight of specimen + paint at testing

G = weight of specimen in air

H = weight of failed specimen

I = weight of oven-dry specimen

$\gamma\omega$ = unit weight of water (g/cm^3)

5. Loads (LBS) = 312.6 + 14.37 (D.R.)

where

D.R. = Dial Reading in increments

6. Adjusted stability (LBS) = Load x C.R.

where

C.R. = Correlation Ratio

3.3.5 Results

As the laboratory experimental work was performed, data were collected and recorded in various table forms. The data were then summarized and kept in table-form data sheets. Table 12 is a sample data sheet constructed for mixes containing 7 percent mineral filler and 3 percent residual asphalt content. From the various data sheets

Table 12

Emulsified Asphalt Mixture Data Sheet

ASPHALT	AGGREGATE
Type & Grade.............CSS-1	Source ID.........Dell Rapids Pit
Asphalt in Emulsion........65%	Type...................Quartzite
Asphalt Spc. Gra..........1.20	Bulk Spec. Grad...............2.66
Residual Asphalt in Mixture................3.0%	Amount of Fines (passing #200 sieve) in Mix............7.0%
MIXING AND COMPACTION	**TESTING**
Total Mix Water...........5.0%	Specimen Test Date (2 Day Cure)...............4-12-88
Added Mix Water..........33.5g	Specimen Test Date (3 Day Cure)...............4-13-88
Water at Compaction.......5.0%	
Compaction Date........4-10-88	

COMPACTED SPECIMEN DATA	2 Day Curing*		3 Day Curing	
	1	2	3	4
BULK DENSITY				
wt. of spec. in air, gms.......	989.2	998.5	964.4	988.0
wt. of spec. + paint in air, gms....................	1000.1	1009.6	978.3	1002.4
wt. of spec. + paint in water, gms..................	514.2	519.9	517.9	527.5
wt. of spec. + paint at SSD condition..................	1002.4	1012.3	979.9	1004.1
wt. of spec. + paint at testing......................	999.1	1009.2	976.2	1000.3
BSG-Compacted Mix.............	2.090	2.096	2.164	2.150
Dry BSG-Compacted Mix..........	2.082	2.086	2.156	2.141
Thickness (inches)............	2-3/8	2-3/8	2-1/4	2-5/16
STABILITY				
Dial...........................	87	99	117	123
Load, LBS......................	1563	1735	1994	2080
Adjusted Stability, LBS........	1703	1848	2373	2371
Flow, 1/100 in. or 0.25 mm.....	22	23	19	19
MOISTURE CONTENT				
wt. of failed spec., gms.......	999.2	1009.3	976.1	1000.2
wt. of oven dry spec., gms.....	995.6	1004.9	972.4	996.2
Moisture Content (%)...........	0.37	0.45	0.39	0.41
Max. Total Voids (%)...........	18.04	17.89	15.16	15.73

*Curing time includes one day in the mold at room temperature and the remainder out of the mold in the oven at 100°F.

Table 13

Marshall Mix Results

Mineral Fillers %	Rsdl Asph Cont (%)	Flow (1/100 in.)	Stability (LBS)	M.C.[1] (%)	DBSG[2]	MTV[3] (%)
ONE DAY CURING IN OVEN ($100^{o}F$)						
4	3	20.0	1628.0	0.54	2.098	17.43
	4	20.0	1476.0	0.52	2.073	17.25
	5	25.0	1078.0	0.61	2.063	16.48
	6	23.0	915.0	0.80	2.109	13.45
	7	24.0	1085.0	0.56	2.107	12.42
7	3	23.0	1776.0	0.41	2.076	17.97
	4	22.0	1405.0	0.41	2.059	17.81
	5	30.0	1256.0	0.40	2.029	17.85
	6	28.0	856.0	0.58	1.995	18.14
	7	26.0	788.0	0.49	2.007	16.60
10	3	18.0	2289.0	0.42	2.136	15.92
	4	18.0	1651.0	0.33	2.094	16.42
	5	19.0	1487.0	0.39	2.100	14.99
	6	26.0	1363.0	0.57	2.076	14.83
	7	24.0	1101.0	0.60	2.077	13.68
TWO DAYS CURING IN OVER ($100^{o}F$)						
4	3	17.0	1814.0	0.34	2.117	16.66
	4	17.0	1660.0	0.29	2.108	15.83
	5	18.0	1445.0	0.23	2.112	14.51
	6	23.0	1527.0	0.37	2.105	13.63
	7	22.0	1494.0	0.39	2.118	11.96
7	3	19.0	2372.0	0.40	2.148	15.44
	4	20.0	1821.0	0.31	2.117	15.49
	5	21.0	1688.0	0.33	2.114	14.44
	6	26.0	1597.0	0.45	2.109	13.48
	7	22.0	1834.0	0.42	2.134	11.31
10	3	18.0	3086.0	0.31	2.170	14.58
	4	20.0	2554.0	0.27	2.142	14.30
	5	20.0	2087.0	0.33	2.140	13.36
	6	21.0	1993.0	0.44	2.128	12.71
	7	27.0	1693.0	0.46	2.134	11.30

[1] M.C. = Moisture Contnet
[2] DBSG = Dry Bulk Specific Gravity
[3] MTV = Maximum Total Voids

constructed for all types of mixes, the values of properties necessary for analysis were extracted and collected in one table for ease of comparison. Table 13 shows those properties and their values at different mix types. To illustrate and clarify the values in Tables 12 and 13, a sample calculation is shown below.

3.3.6 Sample Calculations

These are calculations for specimen 1 of the mix containing 7 percent mineral fillers, 3 percent residual asphalt, and cured for 1 day in oven:

1. Bulk specific gravity of mix specimen

   a. volume of specimen + paint =

   $$1000.1-514.2-(1002.4-100.1)/1$$
   $$= 483.6\ cm^3$$

   b. volume of paint = $1000.1-989.2/1.0556 \times 1.0$
   $$= 10.326\ cm^3$$

   c. volume of specimen = $483.6-10.326$
   $$= 473.274\ cm^3$$

   d. BSG = $989.2/473.274 = 2.090$

2. Dry BSG = $2.090/1+(0.37/100) = 2.082$

3. Moisture Content at testing (K) =

$$(999.2-995.6)-(999.1-1000.1)/995.6 \times 1/(1-(3/100)) \times 100 = 0.47\%$$

4. Maximum total voids (MTV) =

$$((3/100)+1+(0.37/100)/2.090)-1/2.66-((3/100)/1.02)/((3/100)+1$$
$$+(0.37/100)/2.090) \times 100 = 18.04\%$$

5. Load = 312.6 + 14.37(87) = 1563.0 lbs.

6. Adjusted stability = 1563.0 x 1.09 = 1703.0 lbs.

<u>Note</u> - Table 13 contains averages of the values calculated for the two specimens prepared at each mix type.

CHAPTER 4

DATA ANALYSIS USING BASIC STATISTICAL TECHNIQUES

This section is devoted to the analysis of the data obtained in Chapter 3 and to express some design parameters in terms of various indpendent variables. Stepwise regression utilizing the well known SAS (Statistical Analysis System) program was conducted and prediction models were constructed for each dependent (response) variable considered in this analysis. It is of great importance to note that the independent variables included in all the models, presented later, are deviations from their means. Mathematically speaking, the mean of each variable is subtracted from its value when used in the model, i.e., residual asphalt (%R.A.), mineral filler (%F), and curing time (T), which represent the independent variables, are used in the models as such,

$$\%R.A. = \%R.A.-5$$

$$\%F = \%F-7$$

$$T = \%-1.5$$

where 5, 7, and 1.5 are the means of %R.A., %F, and T respectively. This technique provides more accurate models than if the actual values of the independent variables were used. It reduces the effect of completely associated factors and results in models with smaller deviation. This has been proven by conducting the Analysis of Variance (ANOVA) with colinearity diagnostics on the model for flow. This technique chooses the more important factor among factors that are closely related and uses it in the model, which results in a significant reduction in the variability of the response (dependent) variable.

The major properties of emulsified asphalt-aggregate cold mixes consist of moisture content, dry bulk specific gravity, maximum total voids, Marshall flow, and Marshall stability. Each one of these properties is analyzed and discussed separately in this chapter.

4.1 Moisture Content (MC)

The moisture content was measured at the time of testing, and is expressed as a percentage of the total dry aggregate weight. The percent of residual asphalt, percent of mineral filler, curing time, and the interaction between mineral filler and curing time significantly affected the percentage of moisture retained in the mix. However, curing time has the greatest effect on the percent of MC. This can be seen from stepwise regression, when curing time was the independent variable contained in the best one-variable model found for the prediction of the percent of MC. See Table 13, where the percent of MC ranged from 0.23 percent to 0.80 percent for all the samples, and the difference between one and two days curing in oven reached up to 0.5 percent for the same mix specimen. Moreover, the difference in the percent of MC between one and two days curing in an oven at 4 percent mineral filler was greater than that at the 7 percent and 10 percent levels. Mineral filler has a great surface area, and by increasing its content in the mix, the mix's ability to retain moisture increases and the time it takes to release it also increases. That is explained in the prediction model by the interaction between mineral filler and time. The percentage of residual asphalt was found to have an effect on the amount of moisture retained in the mix. When the percentage of residual asphalt increases, it means that the amount of emulsified asphalt (emulsion) is larger. Since emulsions contain water, the amount of moisture retained was affected by that increase. Figures 9 and 10 show the effect of residual asphalt, mineral filler, and curing time on the moisture content of the mix.

Based on the set of data obtained by the laboratory experimental work, the percentage of moisture content can be predicted for any combination of percentage of residual asphalt, percentage of mineral filler in mix, and curing time by the prediction model shown below:

$$\%MC = 0.433-0.009(\%F)+0.034(\%R.A.)-0.151(T)+0.030(\%F\times T) \qquad (1)$$

where

$\%F$ = percentage mineral filler - 7

$\%R.A.$ = percentage residual asphalt - 5

T = curing time in oven, in days - 1.5

EXAMPLE:

To predict %MC at 10 percent mineral filler, 7 percent residual asphalt, and 2 days curing in oven, the values are entered in the model as follows:

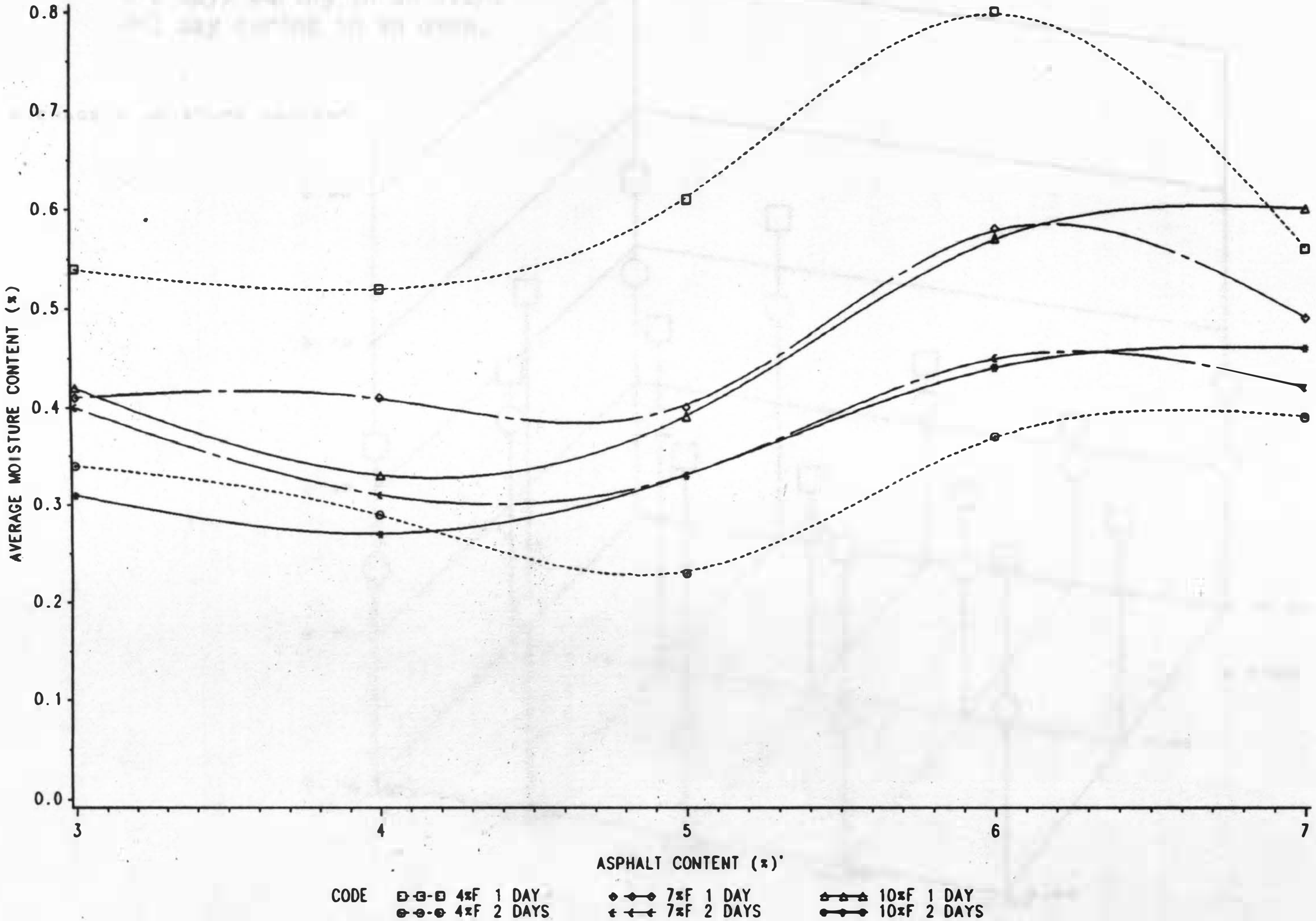

Figure 9. The effect of mineral filler, asphalt content, and curing time on the average moisture content (2D).

o=2 days curing in an oven.
□=1 day curing in an oven.

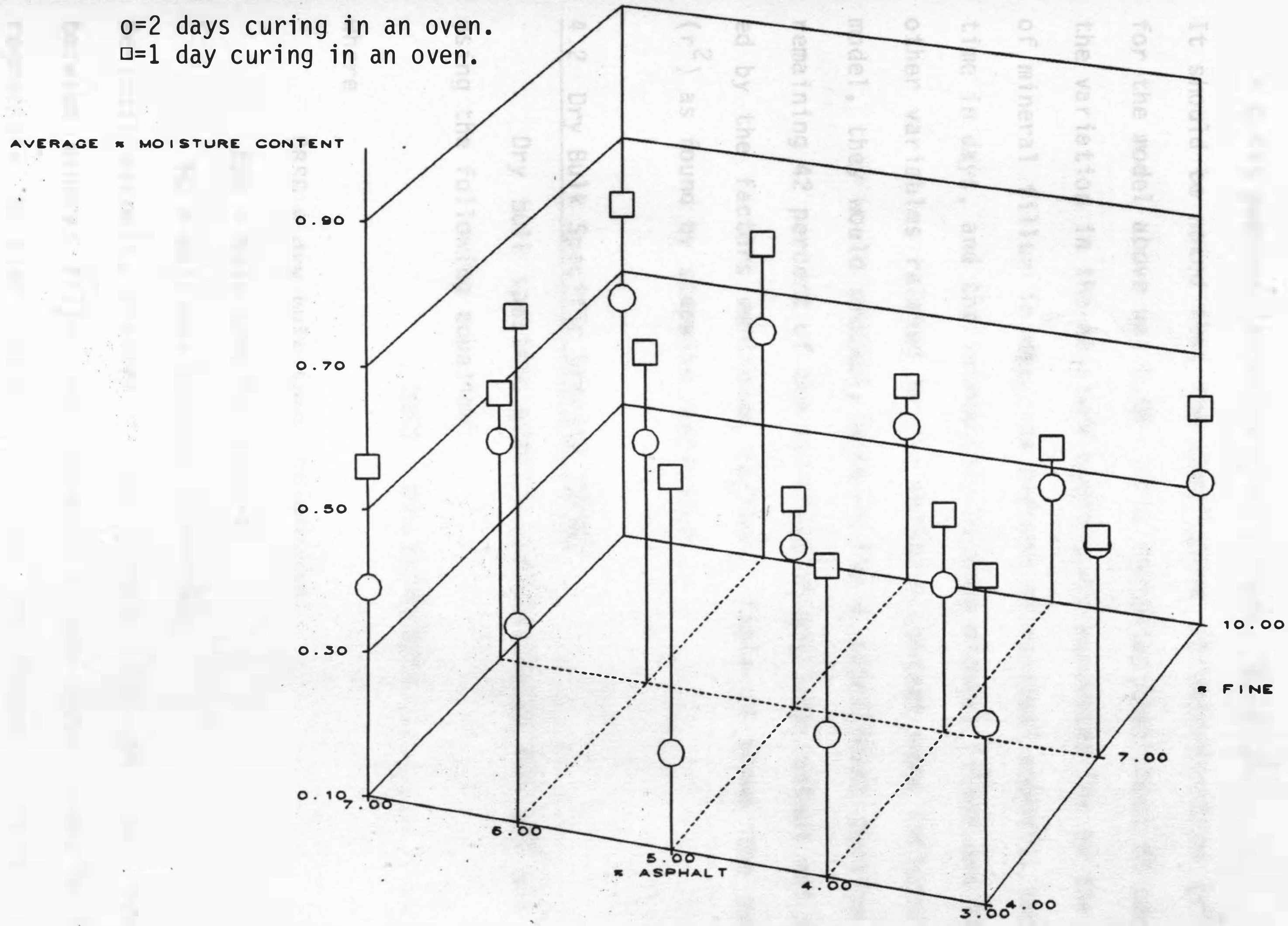

Figure 10. The effect of mineral filler, asphalt content, and curing time on the average moisture content (3D).

$$\%MC = 0.433-0.009(10-7)+0.034(7-5)-0.151(2-1.5)+0.030[(10-7)(2-1.5)]$$

$$= 0.445 \text{ percent (equal to 0.46 percent, Table 13)}$$

It should be noted that the coefficient of determination (r^2) found for the model above was 0.58. This indicates that about 58 percent of the variation in the moisture content was accounted for by the percent of mineral filler in mix, the percent of residual asphalt, the curing time in days, and the interaction between mineral filler and time. If other variables related to the moisture content were included in the model, they would probably account for a significant portion of the remaining 42 percent of the variation in moisture content not explained by the factors mentioned earlier. Table 14 shows the values of (r^2) as found by stepwise regression.

4.2 Dry Bulk Specific Gravity (DBSG)

Dry bulk specific gravity was calculated for all mix samples using the following equation:

$$DBSG = BSG/1+(MC/100)....................(2)$$

where

DBSG = dry bulk specific gravity

BSG = bulk specific gravity

MC = moisture content in percent

Residual asphalt, mineral filler, curing time, and the interaction between mineral filler and residual asphalt were found, by stepwise regression, to significantly influence the dry bulk specific gravity.

Table 14

Appropriate Model to Predict Moisture Content (%MC)

Source	r^2	Cumulative r^2
Curing Time	0.334	0.334
%Residual Asphalt	0.140	0.474
%Fine x Time	0.080	0.554
%Fine	0.028	0.582

%MC=0.433-0.009(%F)+0.034(%R.A.)-0.151(T)+0.030(%FxT)

Yet, the most important factor found to affect the DBSG, and included in the best one-variable prediction model was the curing time. Since DBSG is a function of the moisture content, and time was found to strongly affect the moisture content, it is only logical to find time as the biggest influence on DBSG. Figure 11 shows the effect of mineral filler, residual asphalt, and curing time on the DBSG. The different levels of added asphalt and mineral filler did not contribute, as much as the curing time did, to the variation in the DBSG. As a matter of fact, its value at different levels of residual asphalt and mineral filler was almost the same. Table 13 shows the values of the DBSG at the levels of residual asphalt, mineral filler, and curing time.

From the data obtained by the laboratory experimental work, a prediction model was constructed and expressed as follows:

$$\text{DBSG} = 2.069+0.003(\%F)-0.007(\%R.A.)+0.053(T)-0.002(\%F\times\%R.A.)$$
$$+0.005(\%R.A.)^2+0.003(\%F)^2 \quad \ldots\ldots\ldots\ldots\ldots\ldots (3)$$

where

%R.A. = percentage residual asphalt - 5

%F = percentage mineral filler in mix - 7

T = curing time in oven, in days - 1.5

EXAMPLE:

To predict the DBSG at 10 percent mineral filler, 7 percent residual asphalt, and two days curing in the oven, these values are entered in the model as such:

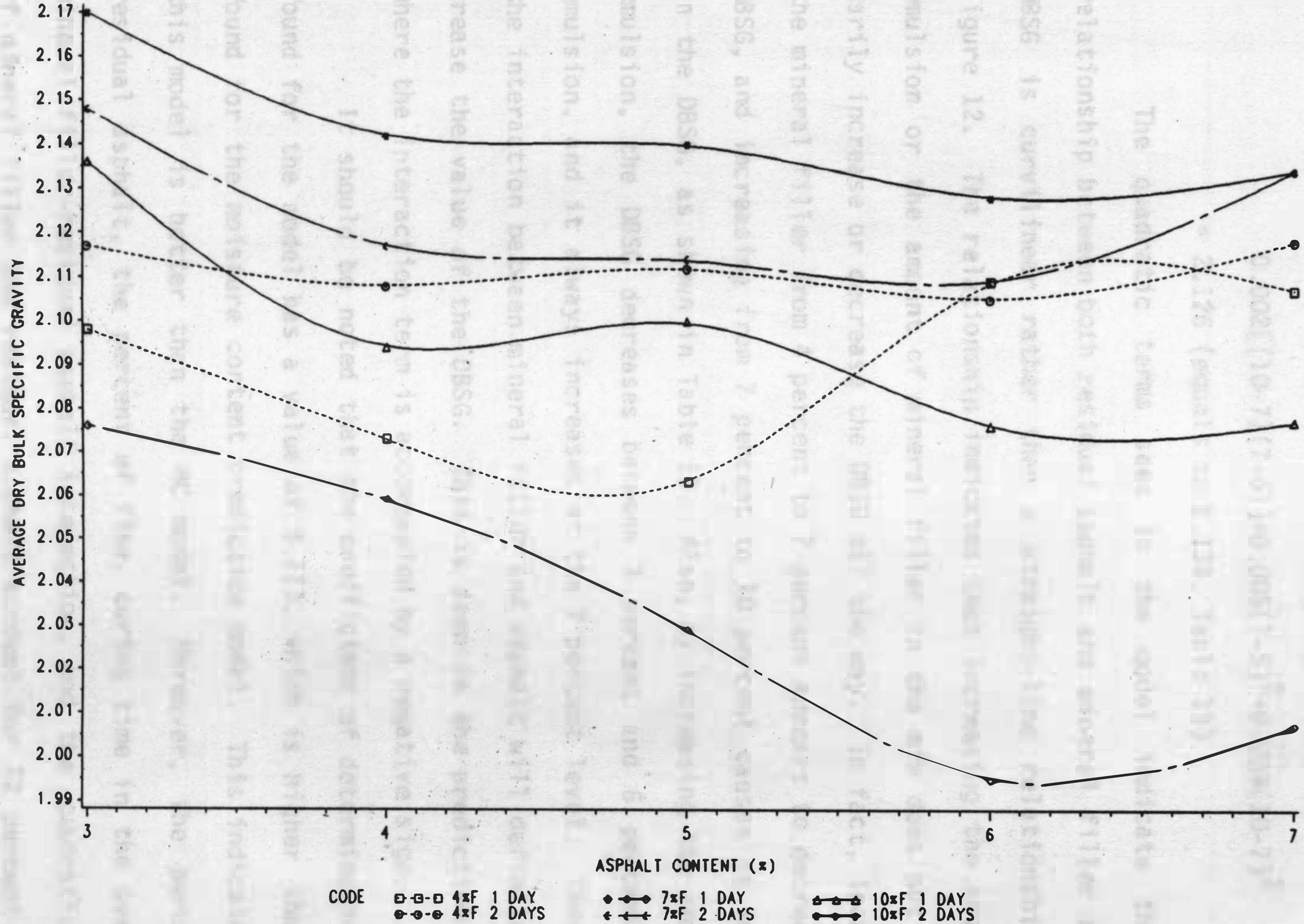

Figure 11. The effect of mineral filler, asphalt content, and curing time on the average dry bulk specific gravity (2D).

$$\begin{aligned} DBSG &= 2.069+0.003(10-7)-0.007(7-5)+0.053(2.15)- \\ &\quad 0.002[(10-7)(7-5)]+0.005(7-5)^2+0.003(10-7)^2 \\ &= 2.126 \text{ (equals to 2.134, Table 13)} \end{aligned}$$

The quadratic terms seen in the model indicate that the relationship between both residual asphalt and mineral filler and the DBSG is curvilinear rather than a straight-line relationship, see Figure 12. The relationship indicates that increasing the amount of emulsion or the amount of mineral filler in the mix does not necessarily increase or decrease the DBSG all the way. In fact, increasing the mineral filler from 4 percent to 7 percent appears to decrease the DBSG, and increasing from 7 percent to 10 percent causes an increase in the DBSG, as shown in Table 13. Also, by increasing the amount of emulsion, the DBSG decreases between 3 percent and 6 percent added emulsion, and it always increases at the 7 percent level. Therefore, the interaction between mineral filler and asphalt will definitely decrease the value of the DBSG. This is seen in the prediction model, where the interaction term is accompanied by a negative sign.

It should be noted that the coefficient of determination (r^2) found for the model has a value of 0.723, which is higher than that found for the moisture content prediction model. This indicates that this model is better than the MC model. Moreover, the percent of residual asphalt, the percent of fine, curing time in the oven, the mineral filler-residual asphalt interaction, and the quadratic terms of mineral filler and residual asphalt account for 72 percent of the

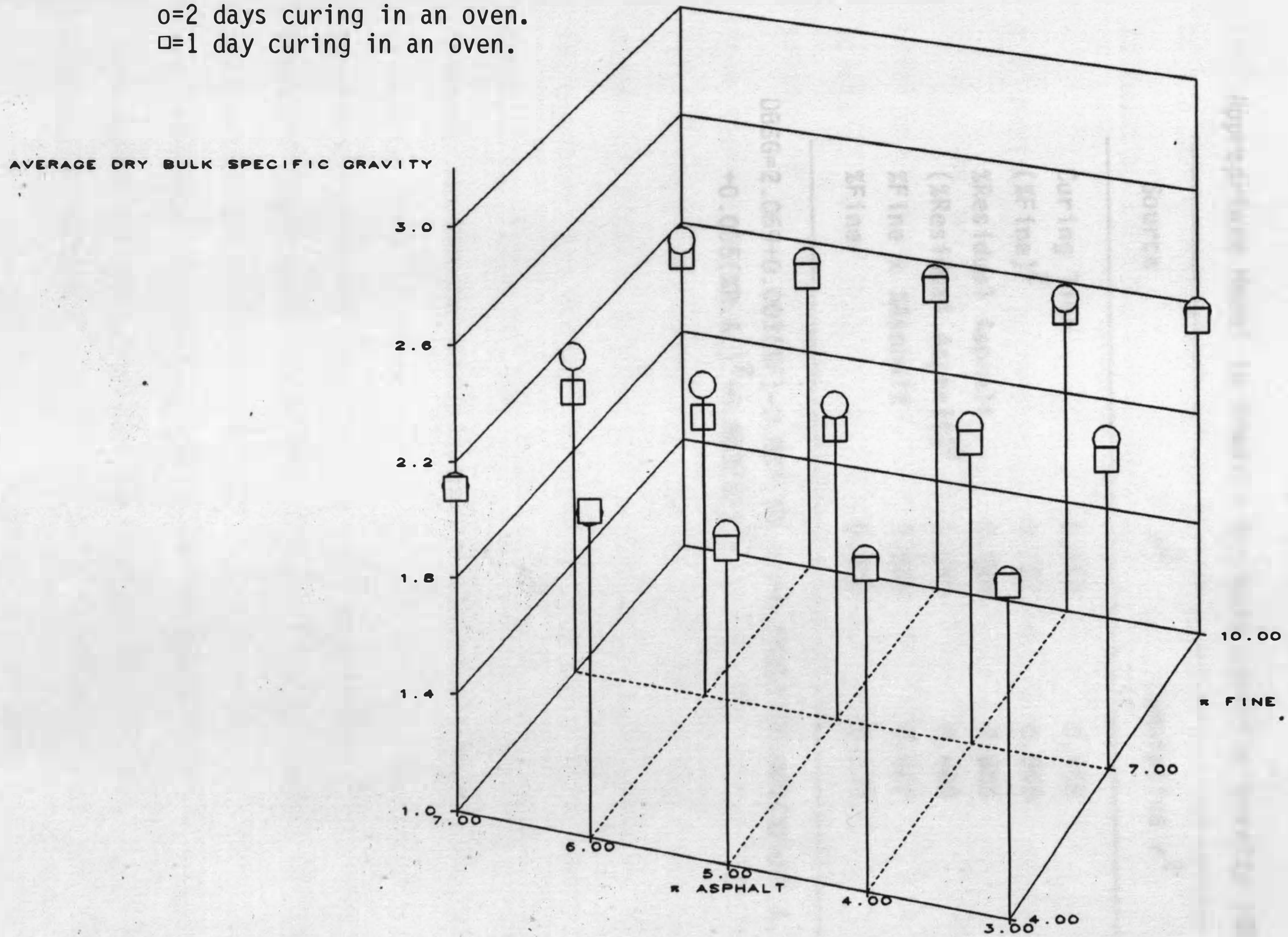

Figure 12. The effect of mineral filler, asphalt content, and curing time on the average dry bulk specific gravity (3D).

Table 15

Appropriate Model to Predict Dry Bulk Specific Gravity (DBSG)

Source	r^2	Cumulative r^2
Curing Time	0.418	0.418
$(\%\text{Fine})^2$	0.127	0.545
%Residual Asphalt	0.060	0.605
$(\%\text{Residual Asphalt})^2$	0.043	0.648
%Fine x %Asphalt	0.039	0.687
%Fine	0.036	0.723

$$\text{DBSG}=2.069+0.003(\%F)-0.007(\%R.A.)+0.053(T)-0.002(\%F\times\%R.A.)$$
$$+0.005(\%R.A.)^2+0.003(\%F)^2$$

variation in the DBSG. The other 28 percent can be accounted for by including new variables, in the prediction model, that may contribute to the determination of the DBSG. Table 15 shows the values of (r^2) as found by stepwise regression.

4.3 Maximum Total Voids (MTV)

The maximum total voids, expressed as a percentage of the total mix volume, includes voids that are filled with both air and moisture. When asphalt is combined with aggregate to form a mix, a portion of the asphalt is absorbed by the aggregate. The remainder, free asphalt, binds aggregate by coating the single particles and filling the voids between various sized particles. Therefore, the degree of binding governs the amount of air and moisture voids. In the meantime, the amount of added asphalt controls the amount of free asphalt available in the mix. As the amount of added asphalt increases, the amount of free asphalt available also increases; consequently, more of the voids between particles are filled. In turn, the number of voids remaining for air and moisture is reduced. This explains the importance of the amount of asphalt added in controlling the maximum total voids (MTV) existing in the mix. These observations are confirmed by stepwise regression analysis, where asphalt was the independent variable included in the best one-variable model found for predicting the MTV.

The amount of mineral filler in the mix affects the MTV in a similar manner, where the mineral filler tends to fill the gaps between the coarser fractions of the aggregate used in the job mix. A reduction in the MTV as the amount of mineral filler in the mix is increased is, therefore, expected. Figures 13 and 14 show the effect of residual asphalt, mineral filler, and curing time in oven on the value of MTV. It is noticed that by increasing the amount of asphalt with different percentages of mineral filler in the mix, the MTV fluctuates at the one day curing time. Furthermore, it takes a drastic increase in the amount of mineral filler added to significantly influence the MTV. Table 13 shows that between 4 percent and 7 percent of mineral filler (at one day curing) the MTV increased slightly when the asphalt is increased to 5 percent and increased drastically at 6 percent and 7 percent asphalt. At between 4 percent and 10 percent of mineral filler, a significant decrease in MTV was noticed up to the 5 percent asphalt level. At the 6 percent and 7 percent asphalt level, the MTV still increased at the one day curing.

However, at two days curing, the picture is even clearer. The continued reduction in the MTV was observed when asphalt and mineral filler were increased. It should be understood that curing time plays a significant role in the determination of the MTV. As the mix is cured for a longer time, more moisture is allowed to evaporate. That aids in the setting of the emulsion and strengthening the binding of the residual asphalt to the aggregate in the mix. In turn, the number

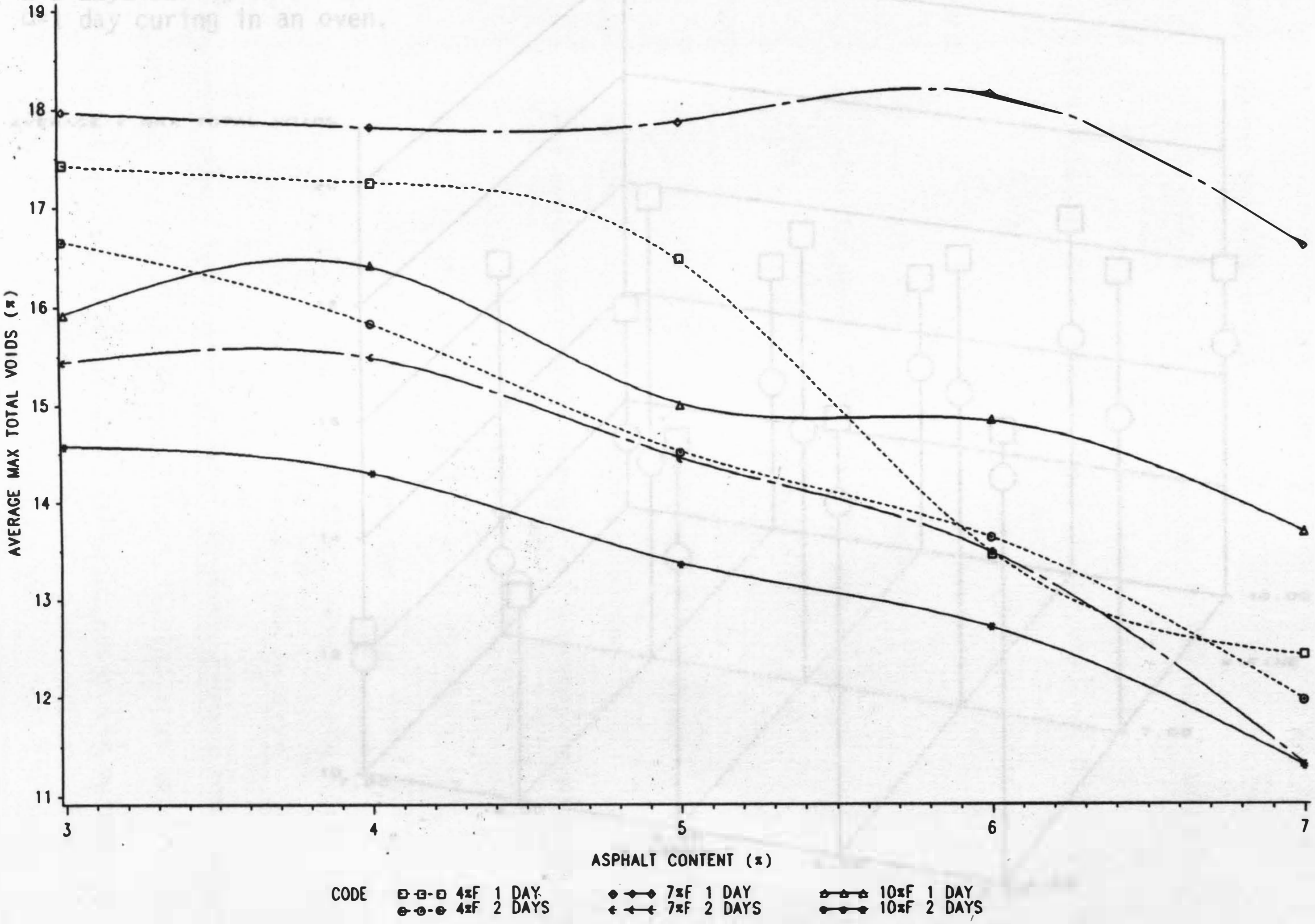

Figure 13. The effect of mineral filler, asphalt content, and curing time on the average maximum total voids (2D).

o=2 days curing in an oven.
□=1 day curing in an oven.

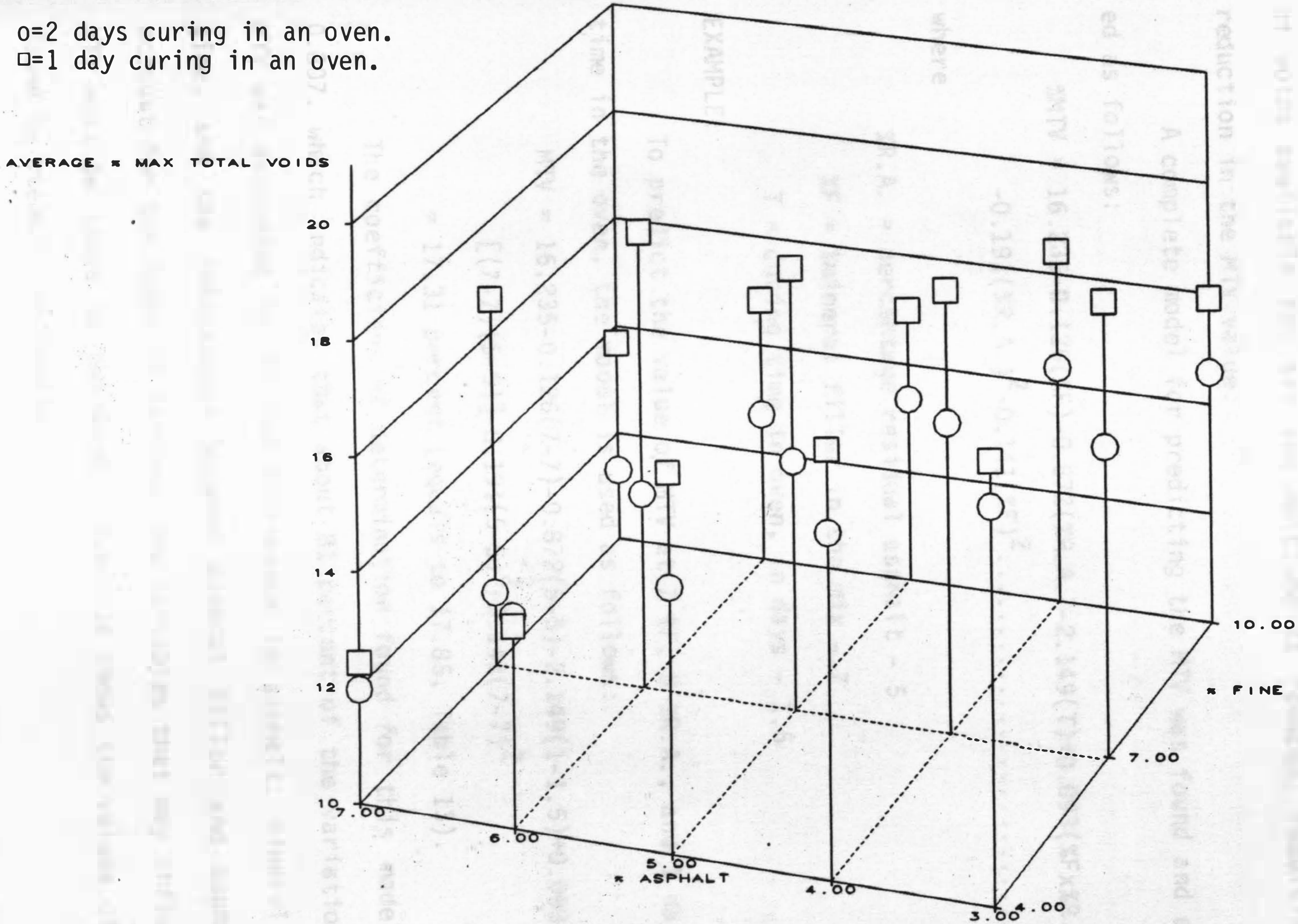

Figure 14. The effect of mineral filler, asphalt content, and curing time on the average maximum total voids (3D).

of voids available for air and moisture is reduced, resulting in a reduction in the MTV value.

A complete model for predicting the MTV was found and expressed as follows:

$$\%MTV = 16.235-0.126(\%F)-0.872(\%R.A.)-2.149(T)+0.093(\%F x \%R.A.) -0.191(\%R.A.)^2-0.141(\%F)^2 \qquad (4)$$

where

%R.A. = percentage residual asphalt - 5

%F = %mineral filler in the mix - 7

T = curing time in oven, in days - 1.5

EXAMPLE:

To predict the value of MTV at 7 %F, 5 %R.A., and 1 day curing time in the oven, the model is used as follows:

$$MTV = 16,235-0.126(7-7)-0.872(5-5)-2.149(1-1.5)+0.093 [(7-7)(5-5)]-0.191(5-5)^2-0.141(7-7)^2$$

$$= 17.31 \text{ percent (equals to 17.85, Table 13).}$$

The coefficient of determination found for this model equals 0.807, which indicates that about 81 percent of the variation in the MTV was accounted for by the difference in asphalt, mineral filler, time, and the interaction between mineral filler and asphalt. To account for the other 19 percent, new variables that may influence the MTV must be added to the model. Table 16 shows the values of (r^2) as found by stepwise regression.

Table 16

Appropriate Model to Predict Maximum Total Voids (%MTV)

Source	r^2	Cumulative r^2
%Residual Asphalt	0.368	0.368
Curing Time	0.279	0.647
$(\%Fine)^2$	0.087	0.734
%Fine x %Asphalt	0.025	0.759
$(\%Residual\ Asphalt)^2$	0.025	0.784
%Fine	0.023	0.807

$$\%MTV=16.235-0.126(\%F)-0.872(\%R.A.)-2.149(T)+0.093(\%Fx\%R.A.)$$
$$-0.191(\%R.A.)^2-0.141(\%F)^2$$

4.4 Marshall Stability

Stability is defined as the ability of an asphalt paving mix to resist deformation from imposed loads. It depends on the internal friction and cohesion provided mainly by the amount of asphalt in the mix. An unstable asphaltic pavement is usually marked by channels (ruts) and corrugation. In hot mixes, the stability increases by adding more asphalt cement until it reaches a peak, and then it starts to decrease. Yet, in cold mixes the dry stability will decrease all the way as the amount of emulsion is increased. Figure 15 shows general trends of the stability curve in hot and cold mixes.

From the data obtained by the laboratory experimental work, Figures 16 and 17 were constructed to show the effect of asphalt, fine, and curing time on the dry stability of cold mixes. It is shown that at any fixed level of added fine, the dry stability does decrease as the percentage of residual asphalt in the mix is increased. Moreover, the stepwise regression showed that asphalt was found to influence stability the most. Asphalt was included as the independent variable in the best one-variable model found for predicting stability. Residual asphalt is a relatively soft material. When it is increased in the mix at dry conditions, it tends to soften the mix and in turn reduces its stability value.

Mineral filler was found to be in direct relationship to dry stability, only if increased by large margins. Table 13 shows that with between 4 percent and 7 percent of added mineral filler,

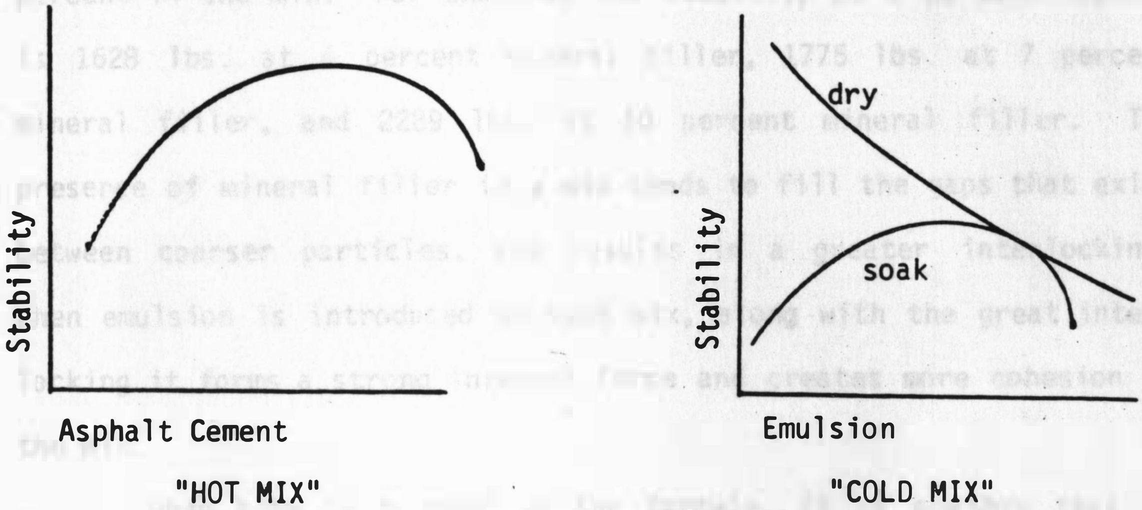

Figure 15. General trends of the stability curve in hot and cold mixes.

stability values at the same asphalt levels are very closely related. In Figure 16 the curves at 4 percent and 7 percent mineral filler intersect at 3 points. However, there is a noticeable difference in stability when the mineral filler was increased from 4 percent to 10 percent in the mix. For example, the stability at 3 percent asphalt is 1628 lbs. at 4 percent mineral filler, 1775 lbs. at 7 percent mineral filler, and 2289 lbs. at 10 percent mineral filler. The presence of mineral filler in a mix tends to fill the gaps that exist between coarser particles, and results in a greater interlocking. When emulsion is introduced to such mix, along with the great interlocking it forms a strong internal force and creates more cohesion in the mix.

When time is entered in the formula, it is obvious that it increases the stability at all levels of residual asphalt and added mineral filler, see Figure 16 and 17. Slow setting emulsions (SS), as the name implies, take a longer time to set (cure), obviously longer than medium setting (MS) or rapid setting (RS) emulsions would take. When the emulsion is given enough time to set (cure), the bond it creates with the aggregate becomes stronger, and more stability is gained in the mix.

A prediction model involving the factors discussed earlier was found by stepwise regression. The model takes this form:

$$\begin{aligned} STAB = {} & 1419.63+86.38(\%F)-204.29(\%R.A.)+567.39(T) \\ & -29.92(\%F\times\%R.A.)+58.86(\%F\times T)+59.81(\%R.A.)^2 \\ & +14.67(\%F)^2 \quad \ldots\ldots (5) \end{aligned}$$

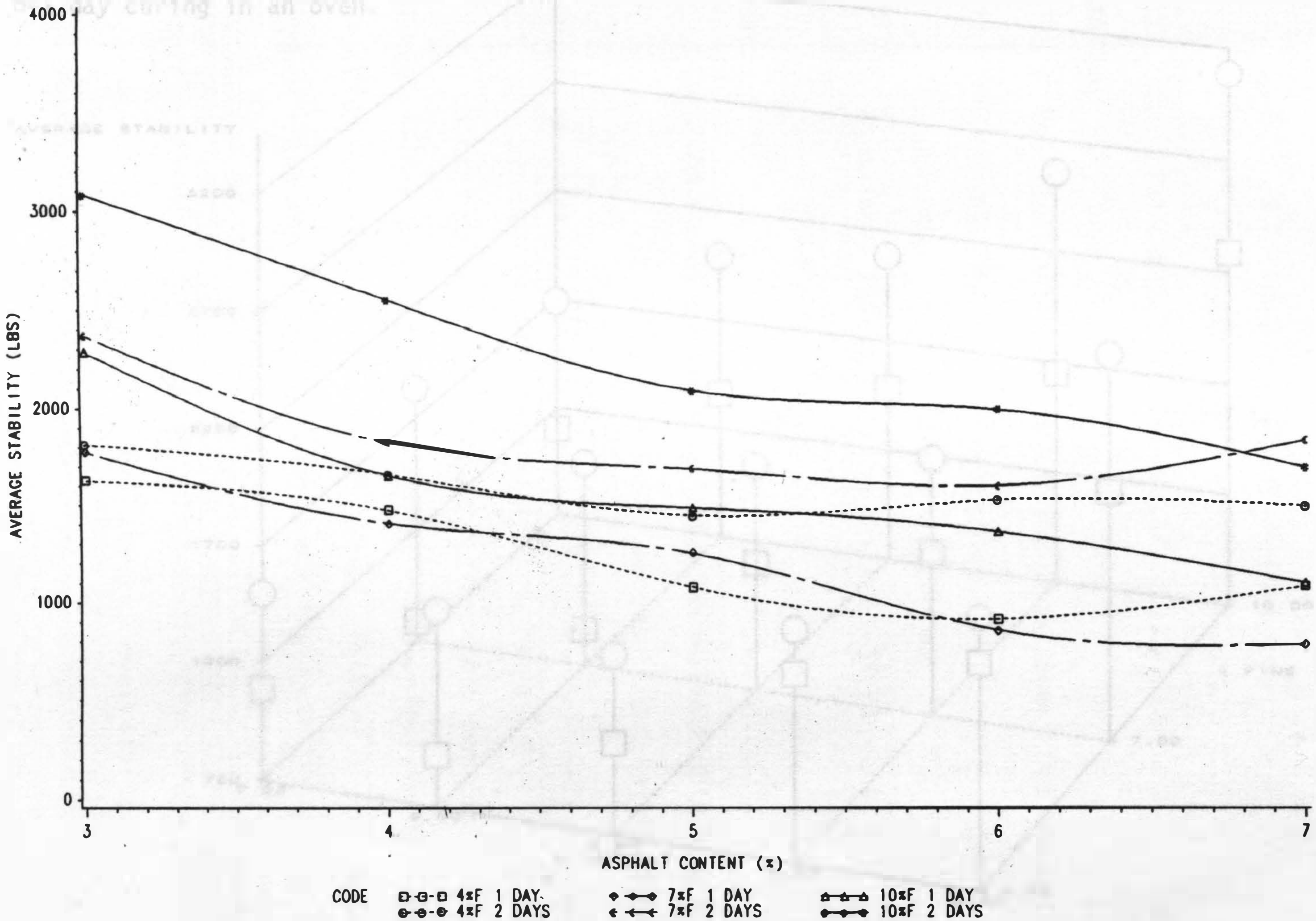

Figure 16. The effect of mineral fines, asphalt content, and curing time on the average stability (2D).

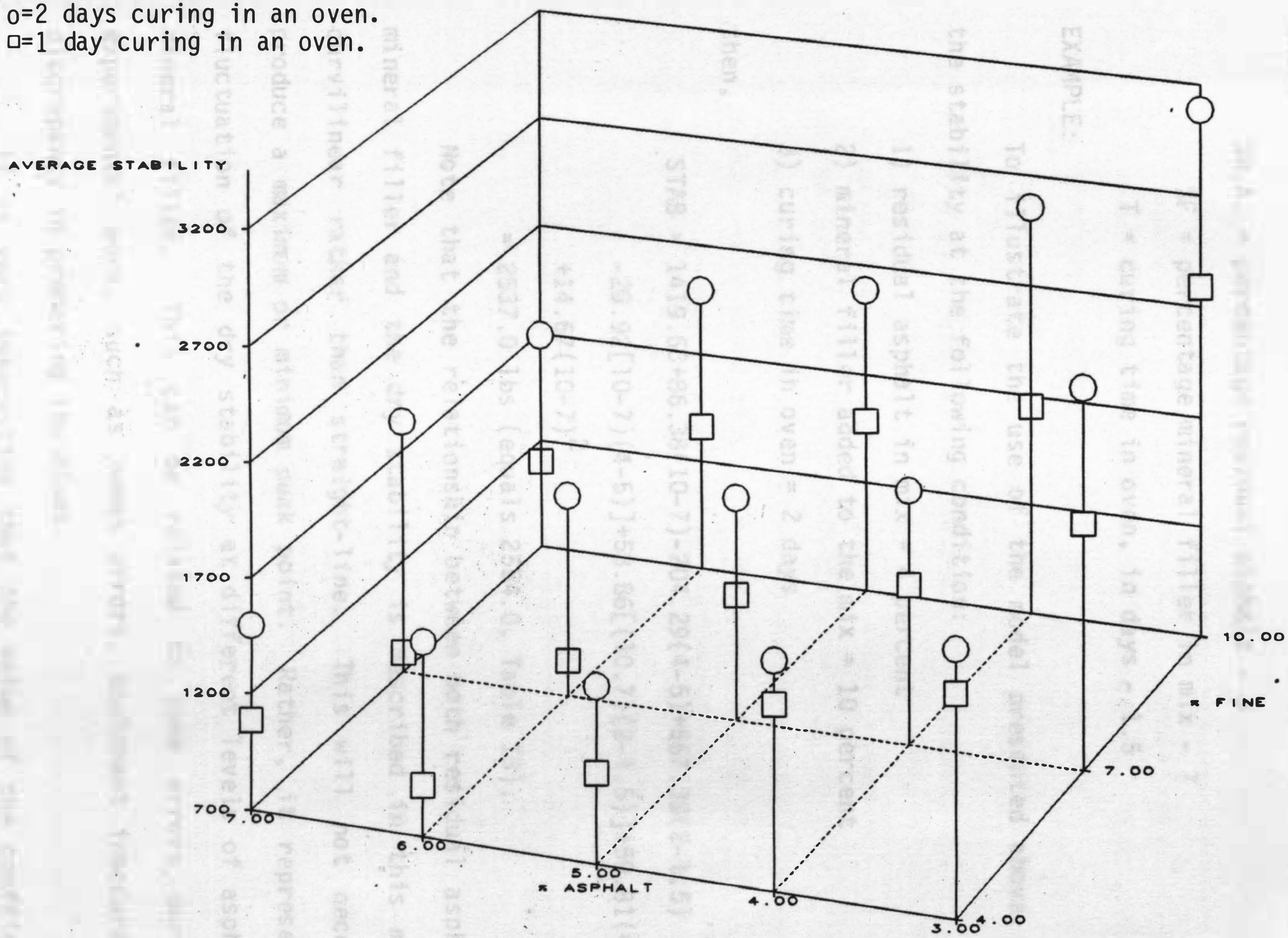

Figure 17. The effect of mineral filler, asphalt content, and curing time on the average flow (2D).

where

%R.A. = percentage residual asphalt - 5

%F = percentage mineral filler in mix - 7

T = curing time in oven, in days - 1.5

EXAMPLE:

To illustrate the use of the model presented above, predict the stability at the following condition:

1) residual asphalt in mix = 4 percent

2) mineral filler added to the mix = 10 percent

3) curing time in oven = 2 days

then,

$$\begin{aligned} STAB &= 1419.63+86.38(10-7)-204.29(4-5)+567.39(2-1.5) \\ &\quad -29.92[10-7)(4-5)]+58.86[(10.7)(2-1.5)]+59.81(4-5)^2 \\ &\quad +14.67(10-7)^2 \\ &= 2537.0 \text{ lbs (equals 2554.0, Table 13).} \end{aligned}$$

Note that the relationship between both residual asphalt and mineral filler and the dry stability is described in this model as curvilinear rather than straight-line. This will not necessarily produce a maximum or minimum peak point. Rather, it represents the fluctuation of the dry stability at different levels of asphalt and mineral filler. This can be related to some errors during the experimental work, such as human errors, equipment inaccuracy, and discrepancy in preparing the mixes.

It is very interesting that the value of the coefficient of determination (r^2) found for the model used to predict the dry

Table 17

Appropriate Model to Predict Marshall Stability (STAB.)

Source	r^2	Cumulative r^2
%Residual Asphalt	0.325	0.325
Curing Time	0.314	0.639
%Fine	0.174	0.813
%Fine x %Asphalt	0.042	0.855
(%Residual Asphalt)^2	0.039	0.894
%Fine x Time	0.021	0.915
%Fine	0.015	0.930

$$\text{STAB.}=1419.63+86.38(\%F)-204.29(\%R.A.)+567.39(T)-29.92(\%F\times\%R.A.)+58.86(\%F\times T)+59.81(\%R.A.)^2+14.67(\%F)^2$$

stability is at 0.929. This is a high value for (r^2), and it means that about 93 percent of the variation in the dry stability is accounted for by the factors and the specified interactions utilized by the model. Table 17 shows the values of (r^2) found by stepwise regression.

4.5 Marshall Flow

Flow is defined as the movement, in units of 0.25 millimeter (1/100 in.), occurring in the specimen between no load and maximum load during the stability test (16). A softer specimen allows more movement than a harder one will. The maximum load referred to here is actually the stability of the specimen. Obviously, specimens with higher stabilities (harder) will exhibit less flow, and vice versa. It was shown earlier that stability generally decreases when the amount of emulsion in mix is increased.

The opposite of the emulsion-stability relationship very much applies to the emulsion-flow relationship. This means that as asphalt increases in the mix, the flow also increases. According to the data obtained by laboratory experiments and statistical analysis using stepwise regression, asphalt is of great importance to flow determination. In the best one-variable model found to predict flow, asphalt was present as the independent variable. Figures 18 and 19 show that at any fixed level of added mineral filler, the flow generally increases with the increase of asphalt in the mix. Yet, at fixed levels of asphalt, the mineral filler were found to form a curvilinear relationship with the flow. This indicates that the flow will increase with increasing the mineral filler up to a certain level, and then it will start to decrease. That level was observed at 7 percent mineral filler. Table 13 shows the values of flow at different levels of asphalt and fine in the mix for the two periods of curing time in the oven. The maximum flow occurred at 7 percent mineral filler in the two stages of curing.

Curing time is very important to the flow. Table 13 shows that at two days curing in the oven, the flow was less than at one day. Prolonged curing aids in strengthening the bond between asphalt and aggregate in a mix. As a result, a harder, more stable mix is formed. In turn, less movement or strain occurs between no load and maximum load during the stability test, and low flow values are obtained.

A prediction model for the flow was obtained by stepwise regression and is presented below:

$$FLOW = 23.5+0.025(\%F)+1.475(\%R.A.)-2.3(T)-0.314(\%F)^2 \quad .....(6)$$

where

%R.A. = percentage residual asphalt - 5

%F = percentage mineral filler in mix - 7

T = curing time in oven, in days - 1.5

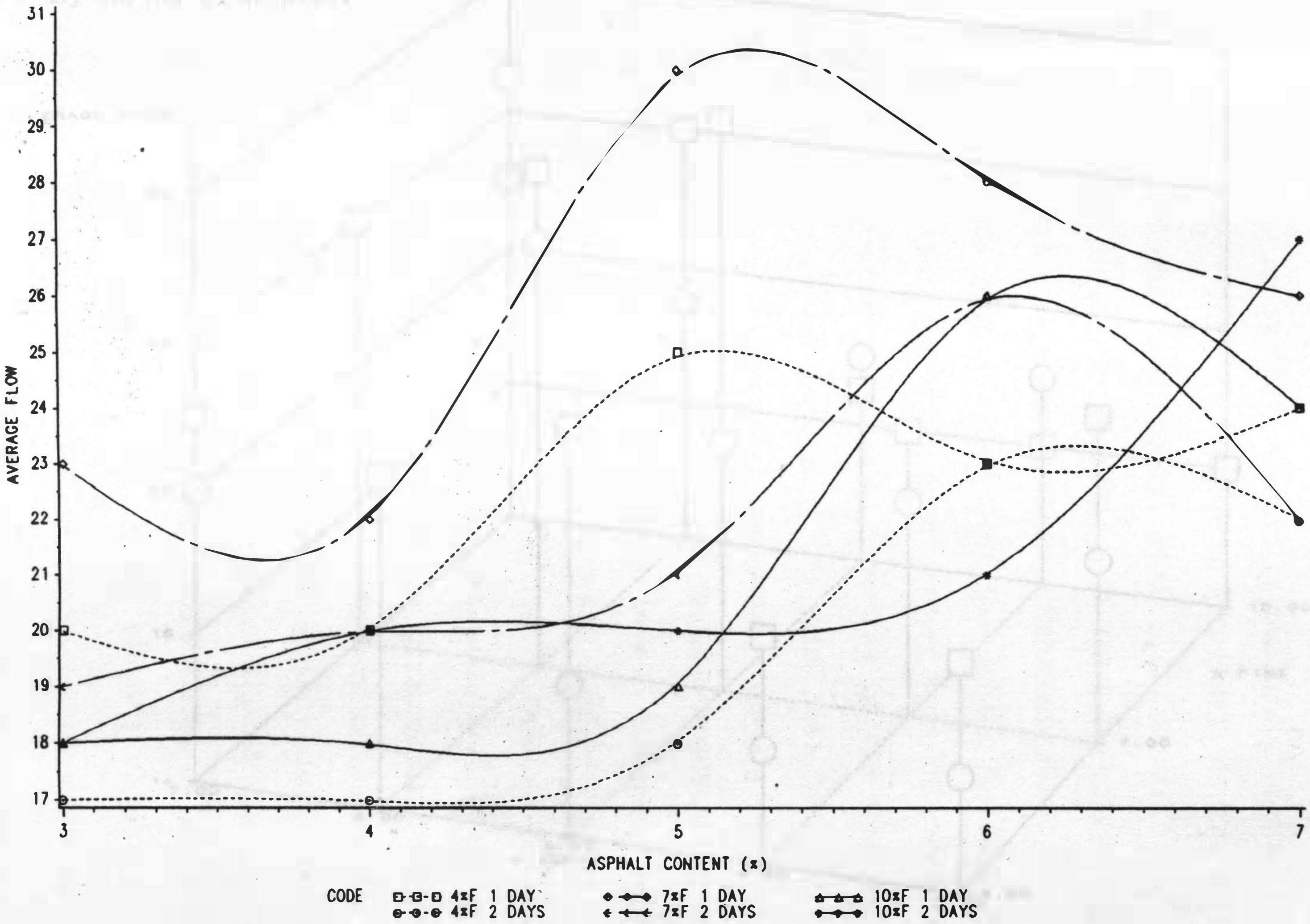

Figure 18. The effect of mineral filler, asphalt content, and curing time on the average flow (2D).

o=2 days curing in an oven.
□=1 day curing in an oven.

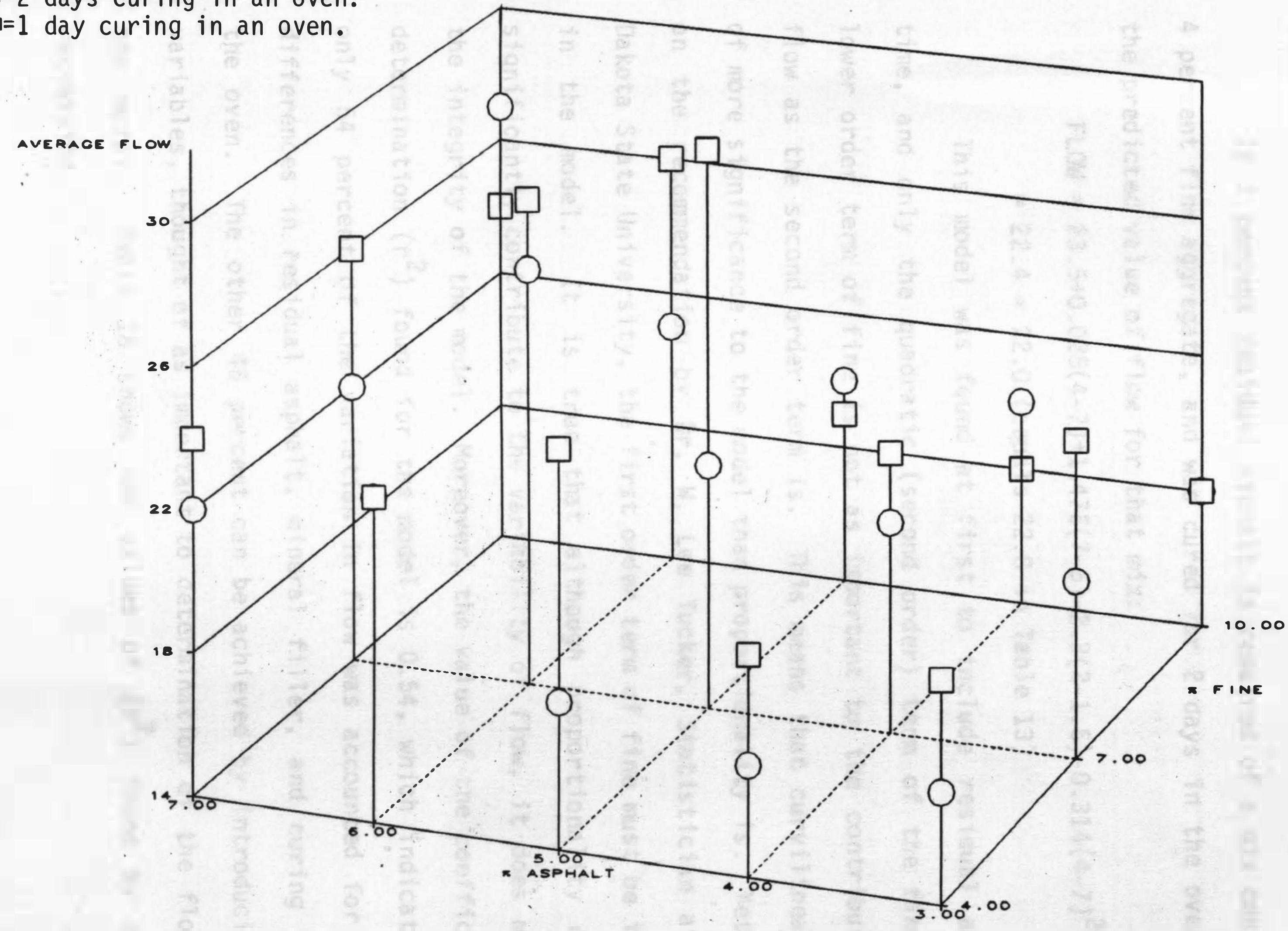

Figure 19. The effect of mineral filler, asphalt content, and curing time on the average flow (3D).

EXAMPLE:

If 7 percent residual asphalt is required of a mix containing 4 percent fine aggregate, and was cured for 2 days in the oven, find the predicted value of flow for that mix:

$$FLOW = 23.5+0.025(4-7)+1.475(7-5)-2.3(2-1.5)-0.314(4-7)^2$$
$$= 22.4 \simeq 22.0 \text{ (equals 22.0 in Table 13)}$$

This model was found at first to include residual asphalt, time, and only the quadratic (second order) term of the fine. The lower order term of fine is not as important to the contribution of flow as the second order term is. This means that curvilinearity is of more significance to the model than proportionality is. Yet, based on the recommendation by Dr. W. Lee Tucker, Statistician at South Dakota State University, the first order term of fine must be included in the model. It is true that although proportionality did not significantly contribute to the variability of flow, it does maintain the integrity of the model. Moreover, the value of the coefficient of determination (r^2) found for the model is 0.54, which indicates that only 54 percent of the variation in flow was accounted for by the differences in residual asphalt, mineral filler, and curing time in the oven. The other 46 percent can be achieved by introducing more variables, thought of as important to determination of the flow, into the model. Table 18 shows the values of (r^2) found by stepwise regression.

Table 18

Appropriate Model to Predict Marshall Flow

Source	r^2	Cumulative r^2
%Residual Asphalt	0.315	0.315
$(\%Fine)^2$	0.129	0.444
Curing Time	0.096	0.540
%Fine	0.000	0.540

$$FLOW = 23.5+0.025(\%F)+1.475(\%R.A.)-2.3(T)-0.314(\%F)^2$$

CHAPTER 5

SUMMARY AND CONCLUSION

This research study was conducted to examine the behavior of cold mixes when used as a surface course for low-volume roads. The two major factors focused on in the study were the effect of mineral filler and curing time on the cold mix.

The amount of mineral filler varied at three different levels: 4 percent, 7 percent, and 10 percent of the total dry aggregate weight. These percentages are within the permissible range as required by the specifications of the South Dakota Department of Transportation (3), in which 4 percent and 10 percent are the minimum and maximum amount of mineral filler permitted. Therefore, 7 percent is the average value.

The curing time was shifted from one day to two days in an oven at 100°F. This temperature was chosen to simulate field conditions and because it lowers the value of stability of the mix specimens, versus room temperature conditions. This can be accomplished in the filed by allowing the paving mix to cure for two days if built during the hot months of the summer (July-August) when temperatures reach 100°F. Otherwise, for 3 to 4 days if temperatures are lower than 100°F.

Cationic slow-setting type-1 emulsion was used in this research for two reasons. First, its slow-setting characteristic enables us to use it in a mix containing fine aggregates. Second, it is the only emulsion type carrying a positive charge. Thus, increases its mixing ability with the quartzite aggregate that naturally carries a negative charge.

The properties of quartzite aggregate make it desirable for road building uses. It consists of quartz mineral which is known to have a high hardness value (11). The inherent negative charge it carries provides strong adhesion when mixed with a cationic emulsion. In addition, it is readily available in the Midwest region of the United States.

The research experimental work was performed in the laboratory and the procedure followed corresponds to both the Asphalt Institute and the Marshall mix design methods, with minor modifications. the modifications applied to the method of determining the bulk specific gravity of the mix specimens. Gloss Latex enamel was used to coat the specimens before weighing them in water. Also, modifications were applied to the equations used to calculate the bulk specific gravity (B56) and the moisture content of the mix specimens. The data obtained were analyzed by stepwise regression analysis utilizing the well known SAS (Statistical Analysis System) program. Properties such as dry bulk specific gravity (DBSG), moisture content (MC), maximum total voids (MTV), Marshall flow, and Marshall stability were evaluated.

The asphalt emulsion mix (AEM) properties are an outcome of a complex array of factors. Evaluating the mix properties in relation to only a single factor is not sufficient; the interaction of these factors influences the behavioral properties of AEMs and must be considered in the evaluation.

The analysis and evaluation of the test data in this study, however, revealed a number of significant results that pertain to the effect on the mix properties of varying the amount of mineral filler in the mix, and altering the curing period. A summary of the main results follows:

1. When the mix was allowed to cure for two days, it resulted in an improvement in all properties of the cold mix. It increased both stability and the dry bulk specific gravity, and decreased the moisture content and the maximum total voids. It decreased the value of flow, however, those values were still within an acceptable range.

2. When the amount of mineral filler was increased from 4 percent to 7 percent, a decline in all mix properties (except the flow) occurred. An improvement in all properties (except the flow), however, was discovered when the amount of mineral filler was increased to 10 percent. The flow property, on the other hand, improved at 7 percent mineral filler rather than at either 4 percent or 10 percent mineral filler. Yet, the flow value of 10 percent mineral

filler was within acceptable limits. One may conclude that 10 percent added mineral filler will always enhance the cold mix properties, and this quantity is, therefore, recommended.

3. The least amount of residual asphalt always resulted in the highest stability of the mix specimens. It is noticeable that 3 percent residual asphalt (minimum amount added) resulted in the highest stability at all levels of added mineral filler and curing time. However, the stability measured here is the dry stability only, and without determining the soaked stability, an optimum residual asphalt content cannot be determined or found.

In conclusion, a prolonged curing time will always enhance the cold mix properties. Therefore, it is recommended that in field conditions the mix should be allowed to cure enough before opening the pavement to traffic. A similar conclusion can be reached for the amount of mineral filler added, where 10% added mineral filler was found to provide the best results concerning the various mix properties evaluated in this particular study. Since a small variation in results occurred, especially between 4 percent and 7 percent added mineral filler, it is suggested that values of mineral filler higher than 10 percent should be examined in order to reach a more definitive conclusion.

As common in many laboratory experimental work, errors can occur. In this study, however, errors can be due to blunders, machines' inaccuracy, and most importantly due to variation in the compaction procedure, in where half of the specimens were compacted using an automatic compaction machine, and the other half were compacted manually due to a failure of the compaction machine used earlier.

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APPENDIX A

Marshall Mix Data Sheets

Emulsified Asphalt Mixture Data Sheet

ASPHALT	AGGREGATE
Type & Grade..............CSS-1	Source ID..........Dell Rapids Pit
Asphalt in Emulsion........65%	Type....................Quartzite
Asphalt Spc. Gra..........1.20	Bulk Spec. Grad...............2.66
Residual Asphalt in Mixture................3.0%	Amount of Fines (passing #200 sieve) in Mix............4.0%

MIXING AND COMPACTION	TESTING
Total Mix Water...........5.0%	Specimen Test Date (2 Day Cure)...............4-10-88
Added Mix Water..........33.5g	Specimen Test Date (3 Day Cure)...............4-11-88
Water at Compaction.......5.0%	
Compaction Date.........4-8-88	

COMPACTED SPECIMEN DATA	2 Day Curing*		3 Day Curing	
	1	2	3	4
BULK DENSITY				
wt. of spec. in air, gms.......	989.6	980.6	997.5	994.3
wt. of spec. + paint in air, gms....................	1002.5	992.4	1009.1	1003.6
wt. of spec. + paint in water, gms..................	512.5	512.0	526.3	525.8
wt. of spec. + paint at SSD condition...................	1013.1	994.5	1010.8	1005.2
wt. of spec. + paint at testing.....................	1005.8	990.2	1008.0	1002.8
BSG-Compacted Mix.............	2.119	2.099	2.122	2.127
Dry BSG-Compacted Mix..........	2.106	2.090	2.114	2.120
Thickness (inches)............	2-1/2	2-7/16	2-5/16	2-5/16
STABILITY				
Dial..........................	72	106	93	85
Load, LBS.....................	1347	1836	1649	1534
Adjusted Stability, LBS........	1347	1909	1880	1749
Flow, 1/100 in. or 0.25 mm.....	18	22	17	16
MOISTURE CONTENT				
wt. of failed spec., gms.......	1005.4	990.4	1008.0	1002.8
wt. of oven dry spec., gms.....	995.9	986.2	1004.6	999.6
Moisture Content (%)..........	0.64	0.44	0.35	0.33
Max. Total Voids (%)..........	17.12	17.74	16.68	16.55

*Curing time includes one day in the mold at room temperature and the remainder out of the mold in the oven at 100°F.

Emulsified Asphalt Mixture Data Sheet

ASPHALT	AGGREGATE
Type & Grade.............CSS-1	Source ID..........Dell Rapids Pit
Asphalt in Emulsion........65%	Type.....................Quartzite
Asphalt Spc. Gra..........1.20	Bulk Spec. Grad...............2.66
Residual Asphalt in Mixture...............4.0%	Amount of Fines (passing #200 sieve) in Mix...........4.0%

MIXING AND COMPACTION	TESTING
Total Mix Water...........5.0%	Specimen Test Date (2 Day Cure)...............4-10-88
Added Mix Water..........28.0g	Specimen Test Date (3 Day Cure)...............4-11-88
Water at Compaction.......5.0%	
Compaction Date.........4-8-88	

COMPACTED SPECIMEN DATA	2 Day Curing*		3 Day Curing	
	1	2	3	4
BULK DENSITY				
wt. of spec. in air, gms.......	1028.5	986.9	978.6	1029.9
wt. of spec. + paint in air, gms.....................	1040.7	996.0	988.0	1040.2
wt. of spec. + paint in water, gms..................	527.9	507.3	515.4	541.2
wt. of spec. + paint at SSD condition...................	1049.5	1001.2	989.5	1041.7
wt. of spec. + paint at testing.....................	1040.5	995.2	986.9	1039.0
BSG-Compacted Mix..............	2.089	2.078	2.117	2.112
Dry BSG-Compacted Mix..........	2.077	2.068	2.111	2.105
Thickness (inches)............	2-5/8	2-7/16	2-5/16	2-7/16
STABILITY				
Dial...........................	82	81	78	91
Load, LBS......................	1491	1477	1433	1620
Adjusted Stability, LBS........	1431	1521	1634	1685
Flow, 1/100 in. or 0.25 mm.....	20	19	16	18
MOISTURE CONTENT				
wt. of failed spec., gms.......	1040.5	995.1	987.0	1039.1
wt. of oven dry spec., gms.....	1034.9	990.5	984.4	1036.0
Moisture Content (%)..........	0.56	0.48	0.28	0.31
Max. Total Voids (%)..........	17.08	17.42	15.70	15.96

*Curing time includes one day in the mold at room temperature and the remainder out of the mold in the oven at 100°F.

Emulsified Asphalt Mixture Data Sheet

ASPHALT	AGGREGATE
Type & Grade.............CSS-1	Source ID.........Dell Rapids Pit
Asphalt in Emulsion........65%	Type....................Quartzite
Asphalt Spc. Gra..........1.20	Bulk Spec. Grad..............2.66
Residual Asphalt in Mixture...............5.0%	Amount of Fines (passing #200 sieve) in Mix...........4.0%
MIXING AND COMPACTION	**TESTING**
Total Mix Water...........5.0%	Specimen Test Date (2 Day Cure)...............4-10-88
Added Mix Water..........23.0g	Specimen Test Date (3 Day Cure)...............4-11-88
Water at Compaction.......5.0%	
Compaction Date.........4-8-88	

COMPACTED SPECIMEN DATA	2 Day Curing*		3 Day Curing	
	1	2	3	4
BULK DENSITY				
wt. of spec. in air, gms.......	1025.7	1014.4	978.2	1050.4
wt. of spec. + paint in air, gms....................	1039.1	1027.7	986.0	1057.5
wt. of spec. + paint in water, gms..................	525.6	523.5	516.3	551.9
wt. of spec. + paint at SSD condition....................	1043.6	1032.7	987.5	1058.8
wt. of spec. + paint at testing.....................	1038.0	1027.3	985.5	1057.0
BSG-Compacted Mix.............	2.067	2.085	2.123	2.111
Dry BSG-Compacted Mix..........	2.055	2.071	2.118	2.106
Thickness (inches)............	2-9/16	2-9/16	2-5/16	2-7/16
STABILITY				
Dial..........................	60	52	60	84
Load, LBS.....................	1175	1060	1175	1520
Adjusted Stability, LBS........	1128	1028	1339	1550
Flow, 1/100 in. or 0.25 mm.....	27	22	16	19
MOISTURE CONTENT				
wt. of failed spec., gms.......	1037.8	1027.2	985.6	1057.0
wt. of oven dry spec., gms.....	1032.4	1020.8	983.5	1054.6
Moisture Content (%)..........	0.55	0.66	0.22	0.24
Max. Total Voids (%)..........	16.79	16.16	14.27	14.76

*Curing time includes one day in the mold at room temperature and the remainder out of the mold in the oven at 100°F.

Emulsified Asphalt Mixture Data Sheet

ASPHALT	AGGREGATE
Type & Grade..............CSS-1	Source ID..........Dell Rapids Pit
Asphalt in Emulsion........65%	Type.....................Quartzite
Asphalt Spc. Gra..........1.20	Bulk Spec. Grad................2.66
Residual Asphalt in Mixture................6.0%	Amount of Fines (passing #200 sieve) in Mix............4.0%

MIXING AND COMPACTION	TESTING
Total Mix Water...........5.0%	Specimen Test Date (2 Day Cure)................4-10-88
Added Mix Water..........17.5g	Specimen Test Date (3 Day Cure)................4-11-88
Water at Compaction.......5.0%	
Compaction Date.........4-8-88	

COMPACTED SPECIMEN DATA	2 Day Curing*		3 Day Curing	
	1	2	3	4
BULK DENSITY				
wt. of spec. in air, gms.......	1020.6	1058.4	1011.4	1043.5
wt. of spec. + paint in air, gms.....................	1031.9	1072.8	1018.6	1051.6
wt. of spec. + paint in water, gms...................	536.5	544.5	533.5	547.0
wt. of spec. + paint at SSD condition....................	1041.8	1084.1	1020.0	1052.9
wt. of spec. + paint at testing......................	1034.2	1076.2	1018.3	1051.5
BSG-Compacted Mix.............	2.150	2.103	2.121	2.105
Dry BSG-Compacted Mix..........	2.134	2.085	2.114	2.096
Thickness (inches).............	2-9/16	2-11/16	2-3/8	2-7/16
STABILITY				
Dial...........................	47	46	78	78
Load, LBS......................	988	974	1433	1433
Adjusted Stability, LBS........	948	881	1562	1491
Flow, 1/100 in. or 0.25 mm.....	24	21	24	22
MOISTURE CONTENT				
wt. of failed spec., gms.......	1034.3	1076.1	1018.4	1051.6
wt. of oven dry spec., gms.....	1024.8	1064.2	1015.4	1047.4
Moisture Content (%)...........	0.75	0.85	0.31	0.43
Max. Total Voids (%)...........	12.45	14.44	13.27	13.99

*Curing time includes one day in the mold at room temperature and the remainder out of the mold in the oven at 100°F.

Emulsified Asphalt Mixture Data Sheet

ASPHALT	AGGREGATE
Type & Grade.............CSS-1	Source ID..........Dell Rapids Pit
Asphalt in Emulsion........65%	Type.....................Quartzite
Asphalt Spc. Gra..........1.20	Bulk Spec. Grad..............2.66
Residual Asphalt in Mixture................7.0%	Amount of Fines (passing #200 sieve) in Mix............4.0%
MIXING AND COMPACTION	**TESTING**
Total Mix Water...........5.0%	Specimen Test Date (2 Day Cure)...............4-10-88
Added Mix Water..........12.5g	Specimen Test Date (3 Day Cure)...............4-11-88
Water at Compaction.......5.0%	
Compaction Date.........4-8-88	

COMPACTED SPECIMEN DATA	2 Day Curing*		3 Day Curing	
	1	2	3	4
BULK DENSITY				
wt. of spec. in air, gms.......	1016.5	1059.9	1033.1	1040.2
wt. of spec. + paint in air, gms....................	1026.4	1068.9	1040.9	1048.5
wt. of spec. + paint in water, gms..................	532.7	561.1	546.9	549.6
wt. of spec. + paint at SSD condition..................	1028.8	1070.2	1042.3	1049.9
wt. of spec. + paint at testing.....................	1024.9	1066.9	1040.2	1047.8
BSG-Compacted Mix.............	2.109	2.128	2.129	2.124
Dry BSG-Compacted Mix..........	2.097	2.117	2.122	2.115
Thickness (inches)............	2-7/16	2-9/16	2-7/16	2-7/16
STABILITY				
Dial..........................	48	60	78	76
Load, LBS.....................	1002	1175	1433	1404
Adjusted Stability, LBS........	1042	1128	1527	1461
Flow, 1/100 in. or 0.25 mm.....	23	24	22	22
MOISTURE CONTENT				
wt. of failed spec., gms.......	1024.6	1066.7	1040.2	1047.8
wt. of oven dry spec., gms.....	1019.1	1061.4	1036.8	1043.6
Moisture Content (%)..........	0.58	0.54	0.35	0.43
Max. Total Voids (%)..........	12.84	12.01	11.83	12.09

*Curing time includes one day in the mold at room temperature and the remainder out of the mold in the oven at 100°F.

ASPHALT	AGGREGATE
Type & Grade.............CSS-1	Source ID.........Dell Rapids Pit
Asphalt in Emulsion........65%	Type...................Quartzite
Asphalt Spc. Gra..........1.20	Bulk Spec. Grad..............2.66
Residual Asphalt in Mixture................3.0%	Amount of Fines (passing #200 sieve) in Mix............7.0%

MIXING AND COMPACTION	TESTING
Total Mix Water...........5.0%	Specimen Test Date (2 Day Cure)...............4-12-88
Added Mix Water..........33.5g	Specimen Test Date (3 Day Cure)...............4-13-88
Water at Compaction.......5.0%	
Compaction Date........4-10-88	

COMPACTED SPECIMEN DATA	2 Day Curing*		3 Day Curing	
	1	2	3	4
BULK DENSITY				
wt. of spec. in air, gms.......	989.2	998.5	964.4	988.0
wt. of spec. + paint in air, gms....................	1000.1	1009.6	978.3	1002.4
wt. of spec. + paint in water, gms..................	514.2	519.9	517.9	527.5
wt. of spec. + paint at SSD condition...................	1002.4	1012.3	979.9	1004.1
wt. of spec. + paint at testing.....................	999.1	1009.2	976.2	1000.3
BSG-Compacted Mix..............	2.090	2.096	2.164	2.150
Dry BSG-Compacted Mix..........	2.082	2.086	2.156	2.141
Thickness (inches).............	2-3/8	2-3/8	2-1/4	2-5/16
STABILITY				
Dial...........................	87	99	117	123
Load, LBS......................	1563	1735	1994	2080
Adjusted Stability, LBS........	1703	1848	2373	2371
Flow, 1/100 in. or 0.25 mm.....	22	23	19	19
MOISTURE CONTENT				
wt. of failed spec., gms.......	999.2	1009.3	976.1	1000.2
wt. of oven dry spec., gms.....	995.6	1004.9	972.4	996.2
Moisture Content (%)...........	0.37	0.45	0.39	0.41
Max. Total Voids (%)...........	18.04	17.89	15.16	15.73

*Curing time includes one day in the mold at room temperature and the remainder out of the mold in the oven at 100^{o}F.

Emulsified Asphalt Mixture Data Sheet

ASPHALT	AGGREGATE
Type & Grade.............CSS-1	Source ID.........Dell Rapids Pit
Asphalt in Emulsion........65%	Type....................Quartzite
Asphalt Spc. Gra..........1.20	Bulk Spec. Grad..............2.66
Residual Asphalt in Mixture................4.0%	Amount of Fines (passing #200 sieve) in Mix............7.0%

MIXING AND COMPACTION	TESTING
Total Mix Water...........5.0%	Specimen Test Date (2 Day Cure)...............4-12-88
Added Mix Water..........28.0g	Specimen Test Date (3 Day Cure)...............4-13-88
Water at Compaction.......5.0%	
Compaction Date........4-10-88	

COMPACTED SPECIMEN DATA	2 Day Curing*		3 Day Curing	
	1	2	3	4
BULK DENSITY				
wt. of spec. in air, gms.......	1026.1	998.1	1002.1	1013.0
wt. of spec. + paint in air, gms.....................	1035.9	1009.7	1014.1	1024.9
wt. of spec. + paint in water, gms...................	529.9	509.9	528.9	535.4
wt. of spec. + paint at SSD condition....................	1038.3	1013.6	1015.6	1026.5
wt. of spec. + paint at testing......................	1035.6	1010.4	1012.4	1023.2
BSG-Compacted Mix.............	2.076	2.058	2.122	2.125
Dry BSG-Compacted Mix.........	2.069	2.049	2.115	2.118
Thickness (inches)............	2-1/2	2-1/2	2-3/8	2-3/8
STABILITY				
Dial..........................	83	69	91	98
Load, LBS.....................	1505	1304	1620	1721
Adjusted Stability, LBS........	1505	1304	1766	1876
Flow, 1/100 in. or 0.25 mm.....	23	21	20	20
MOISTURE CONTENT				
wt. of failed spec., gms.......	1035.7	1010.8	1012.3	1023.2
wt. of oven dry spec., gms.....	1032.4	1005.5	1009.5	1019.9
Moisture Content (%)...........	0.33	0.48	0.29	0.34
Max. Total Voids (%)...........	17.40	18.21	15.54	15.43

*Curing time includes one day in the mold at room temperature and the remainder out of the mold in the oven at 100^{o}F.

Emulsified Asphalt Mixture Data Sheet

ASPHALT	AGGREGATE
Type & Grade.............CSS-1	Source ID.........Dell Rapids Pit
Asphalt in Emulsion........65%	Type.....................Quartzite
Asphalt Spc. Gra..........1.20	Bulk Spec. Grad...............2.66
Residual Asphalt in Mixture................5.0%	Amount of Fines (passing #200 sieve) in Mix............7.0%
MIXING AND COMPACTION	**TESTING**
Total Mix Water...........5.0%	Specimen Test Date (2 Day Cure)...............4-12-88
Added Mix Water..........23.0g	Specimen Test Date (3 Day Cure)...............4-13-88
Water at Compaction.......5.0%	
Compaction Date........4-10-88	

COMPACTED SPECIMEN DATA	2 Day Curing*		3 Day Curing	
	1	2	3	4
BULK DENSITY				
wt. of spec. in air, gms.......	1004.1	1037.9	1022.2	1010.5
wt. of spec. + paint in air, gms....................	1016.8	1049.4	1035.7	1022.5
wt. of spec. + paint in water, gms..................	507.2	528.3	539.8	532.3
wt. of spec. + paint at SSD condition...................	1019.5	1052.3	1037.6	1024.1
wt. of spec. + paint at testing.....................	1016.5	1049.3	1034.3	1021.0
BSG-Compacted Mix.............	2.029	2.046	2.124	2.117
Dry BSG-Compacted Mix..........	2.021	2.037	2.116	2.111
Thickness (inches)............	2-1/2	2-9/16	2-7/16	2-3/8
STABILITY				
Dial..........................	63	72	86	91
Load, LBS.....................	1218	1347	1548	1620
Adjusted Stability, LBS........	1218	1293	1610	1766
Flow, 1/100 in. or 0.25 mm.....	30	30	21	21
MOISTURE CONTENT				
wt. of failed spec., gms.......	1016.5	1049.2	1034.2	1020.8
wt. of oven dry spec., gms.....	1012.7	1045.1	1030.6	1017.9
Moisture Content (%)...........	0.39	0.41	0.37	0.30
Max. Total Voids (%)...........	18.18	17.52	14.33	14.55

*Curing time includes one day in the mold at room temperature and the remainder out of the mold in the oven at 100^{o}F.

Emulsified Asphalt Mixture Data Sheet

ASPHALT	AGGREGATE
Type & Grade.............CSS-1	Source ID.........Dell Rapids Pit
Asphalt in Emulsion........65%	Type....................Quartzite
Asphalt Spc. Gra..........1.20	Bulk Spec. Grad...............2.66
Residual Asphalt in Mixture...............6.0%	Amount of Fines (passing #200 sieve) in Mix...........7.0%

MIXING AND COMPACTION	TESTING
Total Mix Water...........5.0%	Specimen Test Date (2 Day Cure)...............4-12-88
Added Mix Water..........17.5g	Specimen Test Date (3 Day Cure)...............4-13-88
Water at Compaction.......5.0%	
Compaction Date........4-10-88	

COMPACTED SPECIMEN DATA	2 Day Curing*		3 Day Curing	
	1	2	3	4
BULK DENSITY				
wt. of spec. in air, gms.......	1000.6	1060.8	1005.5	1061.6
wt. of spec. + paint in air, gms....................	1012.8	1073.3	1017.2	1074.3
wt. of spec. + paint in water, gms..................	494.8	523.0	529.0	560.2
wt. of spec. + paint at SSD condition...................	1020.5	1078.2	1018.9	1076.1
wt. of spec. + paint at testing......................	1016.1	1074.7	1015.4	1072.8
BSG-Compacted Mix..............	2.006	2.007	2.115	2.122
Dry BSG-Compacted Mix..........	1.996	1.994	2.107	2.110
Thickness (inches).............	2-1/2	2-11/16	2-3/8	2-1/2
STABILITY				
Dial...........................	38	45	75	95
Load, LBS......................	859	959	1390	1678
Adjusted Stability, LBS........	859	854	1515	1678
Flow, 1/100 in. or 0.25 mm.....	27	28	20	31
MOISTURE CONTENT				
wt. of failed spec., gms.......	1016.2	1074.8	1015.3	1072.7
wt. of oven dry spec., gms.....	1008.0	1067.0	1011.9	1067.2
Moisture Content (%)...........	0.52	0.64	0.36	0.55
Max. Total Voids (%)...........	18.11	18.18	13.54	13.41

*Curing time includes one day in the mold at room temperature and the remainder out of the mold in the oven at 100°F.

Emulsified Asphalt Mixture Data Sheet

ASPHALT	AGGREGATE
Type & Grade.............CSS-1	Source ID.........Dell Rapids Pit
Asphalt in Emulsion........65%	Type.....................Quartzite
Asphalt Spc. Gra..........1.20	Bulk Spec. Grad...............2.66
Residual Asphalt in Mixture................7.0%	Amount of Fines (passing #200 sieve) in Mix............7.0%

MIXING AND COMPACTION	TESTING
Total Mix Water...........5.0%	Specimen Test Date (2 Day Cure)...............4-12-88
Added Mix Water..........12.5g	Specimen Test Date (3 Day Cure)...............4-13-88
Water at Compaction.......5.0%	
Compaction Date........4-10-88	

COMPACTED SPECIMEN DATA	2 Day Curing*		3 Day Curing	
	1	2	3	4
BULK DENSITY				
wt. of spec. in air, gms.......	1037.0	1048.7	989.8	1077.8
wt. of spec. + paint in air, gms....................	1048.4	1057.2	999.3	1088.3
wt. of spec. + paint in water, gms..................	508.8	531.4	527.6	573.1
wt. of spec. + paint at SSD condition...................	1051.4	1066.1	1000.9	1089.7
wt. of spec. + paint at testing.....................	1048.7	1061.2	998.2	1087.0
BSG-Compacted Mix..............	1.972	2.061	2.147	2.139
Dry BSG-Compacted Mix..........	1.962	2.051	2.138	2.130
Thickness (inches)............	2-11/16	2-5/8	2-5/16	2-1/2
STABILITY				
Dial...........................	37	40	92	101
Load, LBS......................	844	887	1635	1764
Adjusted Stability, LBS........	751	825	1904	1764
Flow, 1/100 in. or 0.25 mm.....	30	22	21	22
MOISTURE CONTENT				
wt. of failed spec., gms.......	1048.8	1061.2	998.0	1086.7
wt. of oven dry spec., gms.....	1043.6	1052.5	994.4	1082.2
Moisture Content (%)...........	0.50	0.48	0.39	0.45
Max. Total Voids (%)...........	18.44	14.75	11.14	11.49

*Curing time includes one day in the mold at room temperature and the remainder out of the mold in the oven at 100^{O}F.

Emulsified Asphalt Mixture Data Sheet

ASPHALT	AGGREGATE
Type & Grade.............CSS-1	Source ID.........Dell Rapids Pit
Asphalt in Emulsion.:......65%	Type....................Quartzite
Asphalt Spc. Gra..........1.20	Bulk Spec. Grad..............2.66
Residual Asphalt in Mixture................3.0%	Amount of Fines (passing #200 sieve) in Mix...........10.0%

MIXING AND COMPACTION	TESTING
Total Mix Water...........5.0%	Specimen Test Date (2 Day Cure)...............4-14-88
Added Mix Water..........33.5g	Specimen Test Date (3 Day Cure)...............4-15-88
Water at Compaction.......5.0%	
Compaction Date........4-12-88	

COMPACTED SPECIMEN DATA	2 Day Curing*		3 Day Curing	
	1	2	3	4
BULK DENSITY				
wt. of spec. in air, gms.......	980.9	984.6	959.2	1026.2
wt. of spec. + paint in air, gms....................	993.6	997.1	969.6	1035.6
wt. of spec. + paint in water, gms..................	524.4	521.6	517.5	553.9
wt. of spec. + paint at SSD condition...................	996.1	999.1	971.0	1037.3
wt. of spec. + paint at testing.....................	991.7	995.8	968.3	1034.5
BSG-Compacted Mix..............	2.157	2.133	2.176	2.178
Dry BSG-Compacted Mix..........	2.149	2.123	2.169	2.172
Thickness (inches)............	2-5/16	2-5/16	2-1/8	2-5/16
STABILITY				
Dial..........................	125	111	148	162
Load, LBS.....................	2109	1908	2439	2641
Adjusted Stability, LBS........	2404	2175	3163	3009
Flow, 1/100 in. or 0.25 mm.....	19	17	17	18
MOISTURE CONTENT				
wt. of failed spec., gms.......	991.8	995.9	968.3	1034.4
wt. of oven dry spec., gms.....	988.1	991.6	965.2	1031.5
Moisture Content (%)...........	0.39	0.45	0.33	0.29
Max. Total Voids (%)...........	15.41	16.43	14.65	14.51

*Curing time includes one day in the mold at room temperature and the remainder out of the mold in the oven at 100°F.

Emulsified Asphalt Mixture Data Sheet

ASPHALT	AGGREGATE
Type & Grade............CSS-1	Source ID.........Dell Rapids Pit
Asphalt in Emulsion........65%	Type.....................Quartzite
Asphalt Spc. Gra..........1.20	Bulk Spec. Grad..............2.66
Residual Asphalt in Mixture...............4.0%	Amount of Fines (passing #200 sieve) in Mix...........10.0%
MIXING AND COMPACTION	**TESTING**
Total Mix Water...........5.0%	Specimen Test Date (2 Day Cure)...............4-14-88
Added Mix Water..........28.0g	Specimen Test Date (3 Day Cure)...............4-15-88
Water at Compaction.......5.0%	
Compaction Date........4-12-88	

COMPACTED SPECIMEN DATA	2 Day Curing*		3 Day Curing	
	1	2	3	4
BULK DENSITY				
wt. of spec. in air, gms.......	1013.7	1010.3	1038.6	972.4
wt. of spec. + paint in air, gms....................	1023.4	1020.2	1049.2	980.5
wt. of spec. + paint in water, gms..................	532.0	525.3	554.0	520.7
wt. of spec. + paint at SSD condition....................	1025.3	1022.4	1051.1	981.8
wt. of spec. + paint at testing.....................	1022.7	1019.2	1048.1	979.5
BSG-Compacted Mix..............	2.111	2.090	2.148	2.157
Dry BSG-Compacted Mix..........	2.104	2.083	2.142	2.151
Thickness (inches)............	2-3/8	2-7/16	2-3/8	2-3/16
STABILITY				
Dial..........................	90	82	141	123
Load, LBS.....................	1606	1491	2339	2080
Adjusted Stability, LBS........	1750	1551	2549	2559
Flow, 1/100 in. or 0.25 mm.....	17	18	19	20
MOISTURE CONTENT				
wt. of failed spec., gms.......	1022.8	1019.2	1048.0	979.5
wt. of oven dry spec., gms.....	1019.6	1016.0	1045.1	977.1
Moisture Content (%)...........	0.33	0.33	0.29	0.26
Max. Total Voids (%)...........	16.02	16.82	14.46	14.11

*Curing time includes one day in the mold at room temperature and the remainder out of the mold in the oven at $100^{\circ}F$.

Emulsified Asphalt Mixture Data Sheet

ASPHALT	AGGREGATE
Type & Grade.............CSS-1	Source ID..........Dell Rapids Pit
Asphalt in Emulsion........65%	Type.....................Quartzite
Asphalt Spc. Gra..........1.20	Bulk Spec. Grad...............2.66
Residual Asphalt in Mixture................5.0%	Amount of Fines (passing #200 sieve) in Mix...........10.0%
MIXING AND COMPACTION	**TESTING**
Total Mix Water...........5.0%	Specimen Test Date (2 Day Cure)...............4-14-88
Added Mix Water..........23.0g	Specimen Test Date (3 Day Cure)...............4-15-88
Water at Compaction.......5.0%	
Compaction Date........4-12-88	

COMPACTED SPECIMEN DATA	2 Day Curing*		3 Day Curing	
	1	2	3	4
BULK DENSITY				
wt. of spec. in air, gms.......	1017.9	1000.5	1008.7	1027.5
wt. of spec. + paint in air, gms.....................	1028.6	1009.6	1020.7	1036.0
wt. of spec. + paint in water, gms..................	534.5	523.7	538.3	547.4
wt. of spec. + paint at SSD condition....................	1030.9	1011.2	1022.7	1037.4
wt. of spec. + paint at testing......................	1027.7	1008.6	1019.7	1035.1
BSG-Compacted Mix..............	2.113	2.103	2.151	2.144
Dry BSG-Compacted Mix..........	2.105	2.095	2.142	2.138
Thickness (inches).............	2-7/16	2-3/8	2-5/16	2-3/8
STABILITY				
Dial...........................	79	72	109	108
Load, LBS......................	1448	1347	1879	1865
Adjusted Stability, LBS........	1506	1468	2142	2032
Flow, 1/100 in. or 0.25 mm.....	19	19	21	18
MOISTURE CONTENT				
wt. of failed spec., gms.......	1027.8	1008.7	1019.8	1035.0
wt. of oven dry spec., gms.....	1023.8	1005.1	1016.1	1032.2
Moisture Content (%)...........	0.41	0.38	0.38	0.29
Max. Total Voids (%)...........	14.80	15.18	13.28	13.45

*Curing time includes one day in the mold at room temperature and the remainder out of the mold in the oven at 100^{o}F.

Emulsified Asphalt Mixture Data Sheet

ASPHALT	AGGREGATE
Type & Grade.............CSS-1	Source ID..........Dell Rapids Pit
Asphalt in Emulsion........65%	Type.....................Quartzite
Asphalt Spc. Gra..........1.20	Bulk Spec. Grad...............2.66
Residual Asphalt in Mixture................6.0%	Amount of Fines (passing #200 sieve) in Mix...........10.0%
MIXING AND COMPACTION	**TESTING**
Total Mix Water...........5.0%	Specimen Test Date (2 Day Cure)...............4-14-88
Added Mix Water..........17.5g	Specimen Test Date (3 Day Cure)...............4-15-88
Water at Compaction.......5.0%	
Compaction Date........4-12-88	

COMPACTED SPECIMEN DATA	2 Day Curing*		3 Day Curing	
	1	2	3	4
BULK DENSITY				
wt. of spec. in air, gms.......	1014.3	1043.8	1030.9	1038.4
wt. of spec. + paint in air, gms.....................	1024.7	1055.9	1038.7	1046.9
wt. of spec. + paint in water, gms..................	528.0	541.9	548.1	551.2
wt. of spec. + paint at SSD condition....................	1026.6	1057.5	1039.9	1048.3
wt. of spec. + paint at testing.....................	1023.6	1054.3	1037.9	1045.9
BSG-Compacted Mix..............	2.092	2.084	2.139	2.136
Dry BSG-Compacted Mix..........	2.818	2.070	2.131	2.124
Thickness (inches).............	2-7/16	2-9/16	2-3/8	2-7/16
STABILITY				
Dial...........................	75	71	107	108
Load, LBS......................	1390	1333	1850	1865
Adjusted Stability, LBS........	1446	1280	2017	1970
Flow, 1/100 in. or 0.25 mm.....	25	26	21	21
MOISTURE CONTENT				
wt. of failed spec., gms.......	1023.7	1054.4	1037.9	1045.9
wt. of oven dry spec., gms.....	1019.2	1047.9	1034.5	1040.7
Moisture Content (%)...........	0.47	0.66	0.35	0.53
Max. Total Voids (%)...........	14.59	15.07	12.57	12.85

*Curing time includes one day in the mold at room temperature and the remainder out of the mold in the oven at 100°F.

Emulsified Asphalt Mixture Data Sheet

ASPHALT	AGGREGATE
Type & Grade.............CSS-1	Source ID..........Dell Rapids Pit
Asphalt in Emulsion........65%	Type.....................Quartzite
Asphalt Spc. Gra..........1.20	Bulk Spec. Grad...............2.66
Residual Asphalt in Mixture................7.0%	Amount of Fines (passing #200 sieve) in Mix...........10.0%

MIXING AND COMPACTION	TESTING
Total Mix Water...........5.0%	Specimen Test Date (2 Day Cure)...............4-14-88
Added Mix Water..........12.5g	Specimen Test Date (3 Day Cure)...............4-15-88
Water at Compaction.......5.0%	
Compaction Date........4-12-88	

COMPACTED SPECIMEN DATA	2 Day Curing*		3 Day Curing	
	1	2	3	4
BULK DENSITY				
wt. of spec. in air, gms.......	1043.4	1039.2	1039.1	1048.7
wt. of spec. + paint in air, gms.....................	1054.2	1049.0	1047.8	1058.1
wt. of spec. + paint in water, gms...................	544.0	539.1	553.8	556.8
wt. of spec. + paint at SSD condition....................	1056.3	1050.7	1049.4	1060.9
wt. of spec. + paint at testing......................	1053.3	1047.6	1046.9	1058.1
BSG-Compacted Mix..............	2.096	2.083	2.146	2.142
Dry BSG-Compacted Mix..........	2.083	2.071	2.138	2.130
Thickness (inches).............	2-9/16	2-1/2	2-7/16	2-7/16
STABILITY				
Dial...........................	60	53	91	92
Load, LBS......................	1175	1074	1620	1635
Adjusted Stability, LBS........	1128	1074	1685	1700
Flow, 1/100 in. or 0.25 mm.....	24	23	25	28
MOISTURE CONTENT				
wt. of failed spec., gms.......	1053.3	1047.7	1046.7	1057.8
wt. of oven dry spec., gms.....	1047.4	1041.9	1043.1	1052.5
Moisture Content (%)...........	0.61	0.60	0.37	0.54
Max. Total Voids (%)...........	13.42	13.94	11.14	11.45

*Curing time includes one day in the mold at room temperature and the remainder out of the mold in the oven at 100^{o}F.

APPENDIX B

Stepwise Regression

```
SAS(R) LOG   OS SAS 5.16          VS2/MVS JOB CE04NASR STEP SAS

NOTE: COPYRIGHT (C) 1984,1986 SAS INSTITUTE INC., CARY, N.C.  27511, U.S.A.
NOTE: THE JOB CE04NASR HAS BEEN RUN UNDER RELEASE 5.16 OF SAS AT SOUTH DAKOTA STATE UNIVERSITY (03163001).

NOTE: CPUID   VERSION = FF  SERIAL = 014117  MODEL = 4381 .

NOTE: SAS OPTIONS SPECIFIED ARE:
       SORT=4

        TITLE1 'STEPWISE REGRESSION ANALYSIS'; DATA IT;
        INPUT FINE ASPH SUB TIME A B C D E F G FLOW STAB;
        H=(B- C-(D-B)); I=(B-A)/1.0556; J=H-I; BSG=A/J;
        XYZ=G-B; IF G LE B THEN XYZ=0;
        MC=(((E-F)-(XYZ))/F)*(1/(1-(ASPH/100))); MC=MC*100;
        DBSG=BSG/(1+(MC/100));
        P=(((ASPH/100)+1+(MC/100))/BSG)-(1/2.66)-((ASPH/100)/1.02);
        Q=((ASPH/100)+1+(MC/100))/BSG; MTV=(P/Q)*100;
        FINE=FINE-7; ASPH=ASPH-5; TIME=TIME-1.5; FINE2=FINE**2;
        FIAS=FINE*ASPH; FITI=FINE*TIME; ASTI=ASPH*TIME; ASPH2=ASPH**2;
        CARDS;

NOTE: DATA SET WORK.IT HAS 60 OBSERVATIONS AND 28 VARIABLES. 36 OBS/TRK.
NOTE: THE DATA STATEMENT USED 0.30 SECONDS AND 96K.

        ;
        PROC STEPWISE;
        MODEL DBSG MTV MC FLOW STAB=FINE FINE2 ASPH ASPH2 TIME FIAS FITI ASTI/MAXR
NOTE: THE PROCEDURE STEPWISE USED 0.83 SECONDS AND 272K AND PRINTED PAGES 1 TO 20.
NOTE: SAS USED 272K MEMORY.

NOTE: SAS INSTITUTE INC.
      SAS CIRCLE
      PO BOX 8000
      CARY, N.C. 27511-8000
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STEPWISE REGRESSION ANALYSIS

MAXIMUM R-SQUARE IMPROVEMENT FOR DEPENDENT VARIABLE DBSG

STEP 1 VARIABLE TIME ENTERED R SQUARE = 0.41751608 C(P) = 61.98153333

	DF	SUM OF SQUARES	MEAN SQUARE	F	PROB>F
REGRESSION	1	0.04227901	0.04227901	41.57	0.0001
ERROR	58	0.05898417	0.00101697		
TOTAL	59	0.10126318			

	B VALUE	STD ERROR	TYPE II SS	F	PROB>F
INTERCEPT	2.10031453				
TIME	0.05309049	0.00823395	0.04227901	41.57	0.0001

BOUNDS ON CONDITION NUMBER: 1, 1

THE ABOVE MODEL IS THE BEST 1 VARIABLE MODEL FOUND.

STEP 2 VARIABLE FINE2 ENTERED R SQUARE = 0.54464669 C(P) = 38.23135660

	DF	SUM OF SQUARES	MEAN SQUARE	F	PROB>F
REGRESSION	2	0.05515266	0.02757633	34.09	0.0001
ERROR	57	0.04611052	0.00080896		
TOTAL	59	0.10126318			

	B VALUE	STD ERROR	TYPE II SS	F	PROB>F
INTERCEPT	2.07959928				
FINE2	0.00345254	0.00086547	0.01287365	15.91	0.0002
TIME	0.05309049	0.00734373	0.04227901	52.26	0.0001

BOUNDS ON CONDITION NUMBER: 1, 4

THE ABOVE MODEL IS THE BEST 2 VARIABLE MODEL FOUND.

STEP 3 VARIABLE ASPH ENTERED R SQUARE = 0.60501297 C(P) = 28.00422775

	DF	SUM OF SQUARES	MEAN SQUARE	F	PROB>F
REGRESSION	3	0.06126554	0.02042185	28.59	0.0001
ERROR	56	0.03999764	0.00071424		
TOTAL	59	0.10126318			

	B VALUE	STD ERROR	TYPE II SS	F	PROB>F
INTERCEPT	2.07959928				
FINE2	0.00345254	0.00081323	0.01287365	18.02	0.0001
ASPH	-0.00713727	0.00243968	0.00611288	8.56	0.0050
TIME	0.05309049	0.00690045	0.04227901	59.19	0.0001

BOUNDS ON CONDITION NUMBER: 1, 9

THE ABOVE MODEL IS THE BEST 3 VARIABLE MODEL FOUND.

STEPWISE REGRESSION ANALYSIS

MAXIMUM R-SQUARE IMPROVEMENT FOR DEPENDENT VARIABLE DBSG

STEP 4 VARIABLE ASPH2 ENTERED R SQUARE = 0.64789300 C(P) = 21.31891917

	DF	SUM OF SQUARES	MEAN SQUARE	F	PROB>F
REGRESSION	4	0.06560771	0.01640193	25.30	0.0001
ERROR	55	0.03565547	0.00064828		
TOTAL	59	0.10126318			

	B VALUE	STD ERROR	TYPE II SS	F	PROB>F
INTERCEPT	2.06943144				
FINE2	0.00345254	0.00077476	0.01287365	19.86	0.0001
ASPH	-0.00713727	0.00232429	0.00611288	9.43	0.0033
ASPH2	0.00508392	0.00196439	0.00434217	6.70	0.0123
TIME	0.05309049	0.00657410	0.04227901	65.22	0.0001

BOUNDS ON CONDITION NUMBER: 1, 16

THE ABOVE MODEL IS THE BEST 4 VARIABLE MODEL FOUND.

STEP 5 VARIABLE FIAS ENTERED R SQUARE = 0.68709075 C(P) = 15.37945515

	DF	SUM OF SQUARES	MEAN SQUARE	F	PROB>F
REGRESSION	5	0.06957699	0.01391540	23.71	0.0001
ERROR	54	0.03168619	0.00058678		
TOTAL	59	0.10126318			

	B VALUE	STD ERROR	TYPE II SS	F	PROB>F
INTERCEPT	2.06943144				
FINE2	0.00345254	0.00073710	0.01287365	21.94	0.0001
ASPH	-0.00713727	0.00221130	0.00611288	10.42	0.0021
ASPH2	0.00508392	0.00186889	0.00434217	7.40	0.0088
TIME	0.05309049	0.00625450	0.04227901	72.05	0.0001
FIAS	-0.00234796	0.00090276	0.00396929	6.76	0.0120

BOUNDS ON CONDITION NUMBER: 1, 25

THE ABOVE MODEL IS THE BEST 5 VARIABLE MODEL FOUND.

STEPWISE REGRESSION ANALYSIS

MAXIMUM R-SQUARE IMPROVEMENT FOR DEPENDENT VARIABLE DBSG

STEP 6 VARIABLE FINE ENTERED R SQUARE = 0.72297202 C(P) = 10.11174042

	DF	SUM OF SQUARES	MEAN SQUARE	F	PROB>F
REGRESSION	6	0.07321045	0.01220174	23.05	0.0001
ERROR	53	0.02805273	0.00052930		
TOTAL	59	0.10126318			

	B VALUE	STD ERROR	TYPE II SS	F	PROB>F
INTERCEPT	2.06943144				
FINE	0.00317694	0.00121255	0.00363345	6.86	0.0114
FINE2	0.00345254	0.00070006	0.01287365	24.32	0.0001
ASPH	-0.00713727	0.00210019	0.00611288	11.55	0.0013
ASPH2	0.00508392	0.00177499	0.00434217	8.20	0.0060
TIME	0.05309049	0.00594024	0.04227901	79.88	0.0001
FIAS	-0.00234796	0.00085740	0.00396929	7.50	0.0084

BOUNDS ON CONDITION NUMBER: 1, 36

THE ABOVE MODEL IS THE BEST 6 VARIABLE MODEL FOUND.

STEP 7 VARIABLE FITI ENTERED R SQUARE = 0.73852018 C(P) = 8.96247502

	DF	SUM OF SQUARES	MEAN SQUARE	F	PROB>F
REGRESSION	7	0.07478490	0.01068356	20.98	0.0001
ERROR	52	0.02647828	0.00050920		
TOTAL	59	0.10126318			

	B VALUE	STD ERROR	TYPE II SS	F	PROB>F
INTERCEPT	2.06943144				
FINE	0.00317694	0.00118930	0.00363345	7.14	0.0101
FINE2	0.00345254	0.00068664	0.01287365	25.28	0.0001
ASPH	-0.00713727	0.00205993	0.00611288	12.00	0.0011
ASPH2	0.00508392	0.00174096	0.00434217	8.53	0.0052
TIME	0.05309049	0.00582636	0.04227901	83.03	0.0001
FIAS	-0.00234796	0.00084096	0.00396929	7.80	0.0073
FITI	0.00418258	0.00237860	0.00157446	3.09	0.0846

BOUNDS ON CONDITION NUMBER: 1, 49

THE ABOVE MODEL IS THE BEST 7 VARIABLE MODEL FOUND.

STEPWISE REGRESSION ANALYSIS

MAXIMUM R-SQUARE IMPROVEMENT FOR DEPENDENT VARIABLE DBSG

STEP 8 VARIABLE ASTI ENTERED R SQUARE = 0.74820907 C(P) = 9.00000000

	DF	SUM OF SQUARES	MEAN SQUARE	F	PROB>F
REGRESSION	8	0.07576603	0.00947075	18.94	0.0001
ERROR	51	0.02549715	0.00049994		
TOTAL	59	0.10126318			

	B VALUE	STD ERROR	TYPE II SS	F	PROB>F
INTERCEPT	2.06943144				
FINE	0.00317694	0.00117845	0.00363345	7.27	0.0095
FINE2	0.00345254	0.00068038	0.01287365	25.75	0.0001
ASPH	-0.00713727	0.00204113	0.00611288	12.23	0.0010
ASPH2	0.00508392	0.00172507	0.00434217	8.69	0.0048
TIME	0.05309049	0.00577318	0.04227901	84.57	0.0001
FIAS	-0.00234796	0.00083329	0.00396929	7.94	0.0069
FITI	0.00418258	0.00235689	0.00157446	3.15	0.0819
ASTI	0.00571876	0.00408225	0.00098113	1.96	0.1673

BOUNDS ON CONDITION NUMBER: 1, 64

THE ABOVE MODEL IS THE BEST 8 VARIABLE MODEL FOUND.

STEPWISE REGRESSION ANALYSIS

MAXIMUM R-SQUARE IMPROVEMENT FOR DEPENDENT VARIABLE MTV

STEP 1 VARIABLE ASPH ENTERED R SQUARE = 0.36801013 C(P) = 128.69288870

	DF	SUM OF SQUARES	MEAN SQUARE	F	PROB>F
REGRESSION	1	91.25105956	91.25105956	33.77	0.0001
ERROR	58	156.70694892	2.70184395		
TOTAL	59	247.95800848			

	B VALUE	STD ERROR	TYPE II SS	F	PROB>F
INTERCEPT	15.00725613				
ASPH	-0.87202379	0.15005121	91.25105956	33.77	0.0001

BOUNDS ON CONDITION NUMBER: 1, 1

THE ABOVE MODEL IS THE BEST 1 VARIABLE MODEL FOUND.

STEP 2 VARIABLE TIME ENTERED R SQUARE = 0.64728341 C(P) = 49.07799096

	DF	SUM OF SQUARES	MEAN SQUARE	F	PROB>F
REGRESSION	2	160.49910533	80.24955267	52.30	0.0001
ERROR	57	87.45890314	1.53436672		
TOTAL	59	247.95800848			

	B VALUE	STD ERROR	TYPE II SS	F	PROB>F
INTERCEPT	15.00725613				
ASPH	-0.87202379	0.11307692	91.25105956	59.47	0.0001
TIME	-2.14861267	0.31982982	69.24804577	45.13	0.0001

BOUNDS ON CONDITION NUMBER: 1, 4

THE ABOVE MODEL IS THE BEST 2 VARIABLE MODEL FOUND.

STEP 3   VARIABLE FINE2 ENTERED   R SQUARE = 0.73371298   C(P) = 25.81979151

	DF	SUM OF SQUARES	MEAN SQUARE	F	PROB>F
REGRESSION	3	181.93000827	60.64333609	51.43	0.0001
ERROR	56	66.02800021	1.17907143		
TOTAL	59	247.95800848			

	B VALUE	STD ERROR	TYPE II SS	F	PROB>F
INTERCEPT	15.85245636				
FINE2	-0.14086671	0.03304138	21.43090294	18.18	0.0001
ASPH	-0.87202379	0.09912414	91.25105956	77.39	0.0001
TIME	-2.14861267	0.28036541	69.24804577	58.73	0.0001

BOUNDS ON CONDITION NUMBER: 1,   9

THE ABOVE MODEL IS THE BEST 3 VARIABLE MODEL FOUND.

STEPWISE REGRESSION ANALYSIS

MAXIMUM R-SQUARE IMPROVEMENT FOR DEPENDENT VARIABLE MTV

STEP 4   VARIABLE FIAS ENTERED   R SQUARE = 0.75894689   C(P) = 20.44542670

	DF	SUM OF SQUARES	MEAN SQUARE	F	PROB>F
REGRESSION	4	188.18695848	47.04673962	43.29	0.0001
ERROR	55	59.77104999	1.08674636		
TOTAL	59	247.95800848			

	B VALUE	STD ERROR	TYPE II SS	F	PROB>F
INTERCEPT	15.85245636				
FINE2	-0.14086671	0.03172139	21.43090294	19.72	0.0001
ASPH	-0.87202379	0.09516417	91.25105956	83.97	0.0001
TIME	-2.14861267	0.26916493	69.24804577	63.72	0.0001
FIAS	0.09322129	0.03885061	6.25695021	5.76	0.0198

BOUNDS ON CONDITION NUMBER: 1,   16

THE ABOVE MODEL IS THE BEST 4 VARIABLE MODEL FOUND.

STEP 5 VARIABLE ASPH2 ENTERED R SQUARE = 0.78368158 C(P) = 15.21695282

	DF	SUM OF SQUARES	MEAN SQUARE	F	PROB>F
REGRESSION	5	194.32012417	38.86402483	39.13	0.0001
ERROR	54	53.63788431	0.99329415		
TOTAL	59	247.95800848			

	B VALUE	STD ERROR	TYPE II SS	F	PROB>F
INTERCEPT	16.23459214				
FINE2	-0.14086671	0.03032683	21.43090294	21.58	0.0001
ASPH	-0.87202379	0.09098050	91.25105956	91.87	0.0001
ASPH2	-0.19106789	0.07689256	6.13316568	6.17	0.0161
TIME	-2.14861267	0.25733171	69.24804577	69.72	0.0001
FIAS	0.09322129	0.03714263	6.25695021	6.30	0.0151

BOUNDS ON CONDITION NUMBER: 1, 25

THE ABOVE MODEL IS THE BEST 5 VARIABLE MODEL FOUND.

STEPWISE REGRESSION ANALYSIS

MAXIMUM R-SQUARE IMPROVEMENT FOR DEPENDENT VARIABLE MTV

STEP 6 VARIABLE FINE ENTERED R SQUARE = 0.80662407 C(P) = 10.51223469

	DF	SUM OF SQUARES	MEAN SQUARE	F	PROB>F
REGRESSION	6	200.00889719	33.33481620	36.85	0.0001
ERROR	53	47.94911129	0.90470021		
TOTAL	59	247.95800848			

	B VALUE	STD ERROR	TYPE II SS	F	PROB>F
INTERCEPT	16.23459214				
FINE	-0.12570659	0.05013039	5.68877302	6.29	0.0153
FINE2	-0.14086671	0.02894280	21.43090294	23.69	0.0001
ASPH	-0.87202379	0.08682839	91.25105956	100.86	0.0001
ASPH2	-0.19106789	0.07338338	6.13316568	6.78	0.0119
TIME	-2.14861267	0.24558776	69.24804577	76.54	0.0001
FIAS	0.09322129	0.03544754	6.25695021	6.92	0.0112

BOUNDS ON CONDITION NUMBER: 1, 36

THE ABOVE MODEL IS THE BEST 6 VARIABLE MODEL FOUND.

STEP 7 VARIABLE FITI ENTERED R SQUARE = 0.81740249 C(P) = 9.36234417

	DF	SUM OF SQUARES	MEAN SQUARE	F	PROB>F
REGRESSION	7	202.68149458	28.95449923	33.25	0.0001
ERROR	52	45.27651390	0.87070219		
TOTAL	59	247.95800848			

	B VALUE	STD ERROR	TYPE II SS	F	PROB>F
INTERCEPT	16.23459214				
FINE	-0.12570659	0.04917944	5.68877302	6.53	0.0135
FINE2	-0.14086671	0.02839376	21.43090294	24.61	0.0001
ASPH	-0.87202379	0.08518129	91.25105956	104.80	0.0001
ASPH2	-0.19106789	0.07199133	6.13316568	7.04	0.0105
TIME	-2.14861267	0.24092906	69.24804577	79.53	0.0001
FIAS	0.09322129	0.03477511	6.25695021	7.19	0.0098
FITI	-0.17232390	0.09835888	2.67259739	3.07	0.0857

BOUNDS ON CONDITION NUMBER: 1, 49

THE ABOVE MODEL IS THE BEST 7 VARIABLE MODEL FOUND.

STEPWISE REGRESSION ANALYSIS

MAXIMUM R-SQUARE IMPROVEMENT FOR DEPENDENT VARIABLE MTV

STEP 8 VARIABLE ASTI ENTERED R SQUARE = 0.82548606 C(P) = 9.00000000

	DF	SUM OF SQUARES	MEAN SQUARE	F	PROB>F
REGRESSION	8	204.68588007	25.58573501	30.16	0.0001
ERROR	51	43.27212840	0.84847311		
TOTAL	59	247.95800848			

	B VALUE	STD ERROR	TYPE II SS	F	PROB>F
INTERCEPT	16.23459214				
FINE	-0.12570659	0.04854760	5.68877302	6.70	0.0125
FINE2	-0.14086671	0.02802897	21.43090294	25.26	0.0001
ASPH	-0.87202379	0.08408691	91.25105956	107.55	0.0001
ASPH2	-0.19106789	0.07106641	6.13316568	7.23	0.0097
TIME	-2.14861267	0.23783371	69.24804577	81.61	0.0001
FIAS	0.09322129	0.03432834	6.25695021	7.37	0.0090
FITI	-0.17232390	0.09709521	2.67259739	3.15	0.0819
ASTI	-0.25848182	0.16817383	2.00438550	2.36	0.1305

BOUNDS ON CONDITION NUMBER: 1, 64

THE ABOVE MODEL IS THE BEST 8 VARIABLE MODEL FOUND.

STEPWISE REGRESSION ANALYSIS

MAXIMUM R-SQUARE IMPROVEMENT FOR DEPENDENT VARIABLE MC

STEP 1 VARIABLE TIME ENTERED R SQUARE = 0.33382081 C(P) = 33.78546233

	DF	SUM OF SQUARES	MEAN SQUARE	F	PROB>F
REGRESSION	1	0.34030379	0.34030379	29.06	0.0001
ERROR	58	0.67911673	0.01170891		
TOTAL	59	1.01942052			

	B VALUE	STD ERROR	TYPE II SS	F	PROB>F
INTERCEPT	0.43286662				
TIME	-0.15062178	0.02793911	0.34030379	29.06	0.0001

BOUNDS ON CONDITION NUMBER: 1, 1

THE ABOVE MODEL IS THE BEST 1 VARIABLE MODEL FOUND.

STEP 2 VARIABLE ASPH ENTERED R SQUARE = 0.47348529 C(P) = 16.96193857

	DF	SUM OF SQUARES	MEAN SQUARE	F	PROB>F
REGRESSION	2	0.48268062	0.24134031	25.63	0.0001
ERROR	57	0.53673990	0.00941649		
TOTAL	59	1.01942052			

	B VALUE	STD ERROR	TYPE II SS	F	PROB>F
INTERCEPT	0.43286662				
ASPH	0.03444523	0.00885837	0.14237683	15.12	0.0003
TIME	-0.15062178	0.02505526	0.34030379	36.14	0.0001

BOUNDS ON CONDITION NUMBER: 1, 4

THE ABOVE MODEL IS THE BEST 2 VARIABLE MODEL FOUND.

STEP 3 VARIABLE FITI ENTERED R SQUARE = 0.55427801 C(P) = 8.07295861

	DF	SUM OF SQUARES	MEAN SQUARE	F	PROB>F
REGRESSION	3	0.56504238	0.18834746	23.21	0.0001
ERROR	56	0.45437814	0.00811390		
TOTAL	59	1.01942052			

	B VALUE	STD ERROR	TYPE II SS	F	PROB>F
INTERCEPT	0.43286662				
ASPH	0.03444523	0.00822288	0.14237683	17.55	0.0001
TIME	-0.15062178	0.02325782	0.34030379	41.94	0.0001
FITI	0.03025113	0.00949497	0.08236176	10.15	0.0024

BOUNDS ON CONDITION NUMBER: 1, 9

THE ABOVE MODEL IS THE BEST 3 VARIABLE MODEL FOUND.

STEPWISE REGRESSION ANALYSIS

MAXIMUM R-SQUARE IMPROVEMENT FOR DEPENDENT VARIABLE MC

STEP 4 VARIABLE FINE ENTERED R SQUARE = 0.58239716 C(P) = 6.28315134

	DF	SUM OF SQUARES	MEAN SQUARE	F	PROB>F
REGRESSION	4	0.59370762	0.14842690	19.18	0.0001
ERROR	55	0.42571290	0.00774023		
TOTAL	59	1.01942052			

	B VALUE	STD ERROR	TYPE II SS	F	PROB>F
INTERCEPT	0.43286662				
FINE	-0.00892332	0.00463688	0.02866524	3.70	0.0595
ASPH	0.03444523	0.00803131	0.14237683	18.39	0.0001
TIME	-0.15062178	0.02271598	0.34030379	43.97	0.0001
FITI	0.03025113	0.00927376	0.08236176	10.64	0.0019

BOUNDS ON CONDITION NUMBER: 1, 16

THE ABOVE MODEL IS THE BEST 4 VARIABLE MODEL FOUND.

STEP 5 VARIABLE FIAS ENTERED R SQUARE = 0.59853128 C(P) = 6.10864722

	DF	SUM OF SQUARES	MEAN SQUARE	F	PROB>F
REGRESSION	5	0.61015507	0.12203101	16.10	0.0001
ERROR	54	0.40926545	0.00757899		
TOTAL	59	1.01942052			

	B VALUE	STD ERROR	TYPE II SS	F	PROB>F
INTERCEPT	0.43286662				
FINE	-0.00892332	0.00458833	0.02866524	3.78	0.0570
ASPH	0.03444523	0.00794722	0.14237683	18.79	0.0001
TIME	-0.15062178	0.02247812	0.34030379	44.90	0.0001
FIAS	0.00477951	0.00324444	0.01644745	2.17	0.1465
FITI	0.03025113	0.00917666	0.08236176	10.87	0.0017

BOUNDS ON CONDITION NUMBER: 1, 25

THE ABOVE MODEL IS THE BEST 5 VARIABLE MODEL FOUND.

STEPWISE REGRESSION ANALYSIS

MAXIMUM R-SQUARE IMPROVEMENT FOR DEPENDENT VARIABLE MC

STEP 6 VARIABLE ASPH2 ENTERED R SQUARE = 0.61124792 C(P) = 6.39473943

	DF	SUM OF SQUARES	MEAN SQUARE	F	PROB>F
REGRESSION	6	0.62311868	0.10385311	13.89	0.0001
ERROR	53	0.39630184	0.00747739		
TOTAL	59	1.01942052			

	B VALUE	STD ERROR	TYPE II SS	F	PROB>F
INTERCEPT	0.41529797				
FINE	-0.00892332	0.00455747	0.02866524	3.83	0.0555
ASPH	0.03444523	0.00789377	0.14237683	19.04	0.0001
ASPH2	0.00878432	0.00667145	0.01296361	1.73	0.1936
TIME	-0.15062178	0.02232695	0.34030379	45.51	0.0001
FIAS	0.00477951	0.00322262	0.01644745	2.20	0.1440
FITI	0.03025113	0.00911494	0.08236176	11.01	0.0016

BOUNDS ON CONDITION NUMBER: 1, 36

THE ABOVE MODEL IS THE BEST 6 VARIABLE MODEL FOUND.

STEP 7 VARIABLE ASTI ENTERED R SQUARE = 0.61758295 C(P) = 7.54092567

	DF	SUM OF SQUARES	MEAN SQUARE	F	PROB>F
REGRESSION	7	0.62957673	0.08993953	12.00	0.0001
ERROR	52	0.38984379	0.00749700		
TOTAL	59	1.01942052			

	B VALUE	STD ERROR	TYPE II SS	F	PROB>F
INTERCEPT	0.41529797				
FINE	-0.00892332	0.00456344	0.02866524	3.82	0.0559
ASPH	0.03444523	0.00790411	0.14237683	18.99	0.0001
ASPH2	0.00878432	0.00668019	0.01296361	1.73	0.1943
TIME	-0.15062178	0.02235620	0.34030379	45.39	0.0001
FIAS	0.00477951	0.00322684	0.01644745	2.19	0.1446
FITI	0.03025113	0.00912688	0.08236176	10.99	0.0017
ASTI	-0.01467203	0.01580822	0.00645805	0.88	0.3578

BOUNDS ON CONDITION NUMBER: 1, 49

THE ABOVE MODEL IS THE BEST 7 VARIABLE MODEL FOUND.

STEPWISE REGRESSION ANALYSIS

MAXIMUM R-SQUARE IMPROVEMENT FOR DEPENDENT VARIABLE MC

STEP 8 VARIABLE FINE2 ENTERED R SQUARE = 0.62159644 C(P) = 9.00000000

	DF	SUM OF SQUARES	MEAN SQUARE	F	PROB>F
REGRESSION	8	0.63366817	0.07920852	10.47	0.0001
ERROR	51	0.38575235	0.00756377		
TOTAL	59	1.01942052			

	B VALUE	STD ERROR	TYPE II SS	F	PROB>F
INTERCEPT	0.40361973				
FINE	-0.00892332	0.00458372	0.02866524	3.79	0.0571
FINE2	0.00194637	0.00264641	0.00409144	0.54	0.4654
ASPH	0.03444523	0.00793923	0.14237683	18.82	0.0001
ASPH2	0.00878432	0.00670988	0.01296361	1.71	0.1963
TIME	-0.15062178	0.02245554	0.34030379	44.99	0.0001
FIAS	0.00477951	0.00324118	0.01644745	2.17	0.1465
FITI	0.03025113	0.00916744	0.08236176	10.89	0.0018
ASTI	-0.01467203	0.01587847	0.00645805	0.85	0.3598

BOUNDS ON CONDITION NUMBER: 1, 64

THE ABOVE MODEL IS THE BEST 8 VARIABLE MODEL FOUND.

STEPWISE REGRESSION ANALYSIS

MAXIMUM R-SQUARE IMPROVEMENT FOR DEPENDENT VARIABLE FLOW

STEP 1 VARIABLE ASPH ENTERED R SQUARE = 0.31523817 C(P) = 26.67023164

	DF	SUM OF SQUARES	MEAN SQUARE	F	PROB>F
REGRESSION	1	261.07500000	261.07500000	26.70	0.0001
ERROR	58	567.10833333	9.77772989		
TOTAL	59	828.18333333			

	B VALUE	STD ERROR	TYPE II SS	F	PROB>F
INTERCEPT	21.61666667				
ASPH	1.47500000	0.28544891	261.07500000	26.70	0.0001

BOUNDS ON CONDITION NUMBER: 1, 1

THE ABOVE MODEL IS THE BEST 1 VARIABLE MODEL FOUND.

STEP 2 VARIABLE FINE2 ENTERED R SQUARE = 0.44372220 C(P) = 13.15855416

	DF	SUM OF SQUARES	MEAN SQUARE	F	PROB>F
REGRESSION	2	367.48333333	183.74166667	22.73	0.0001
ERROR	57	460.70000000	8.08245614		
TOTAL	59	828.18333333			

	B VALUE	STD ERROR	TYPE II SS	F	PROB>F
INTERCEPT	23.50000000				
FINE2	-0.31388889	0.08650870	106.40833333	13.17	0.0006
ASPH	1.47500000	0.25952611	261.07500000	32.30	0.0001

BOUNDS ON CONDITION NUMBER: 1, 4

THE ABOVE MODEL IS THE BEST 2 VARIABLE MODEL FOUND.

STEP 3 VARIABLE TIME ENTERED R SQUARE = 0.53953432 C(P) = 3.59130590

	DF	SUM OF SQUARES	MEAN SQUARE	F	PROB>F
REGRESSION	3	446.83333333	148.94444444	21.87	0.0001
ERROR	56	381.35000000	6.80982143		
TOTAL	59	828.18333333			

	B VALUE	STD ERROR	TYPE II SS	F	PROB>F
INTERCEPT	23.50000000				
FINE2	-0.31388889	0.07940649	106.40833333	15.63	0.0002
ASPH	1.47500000	0.23821946	261.07500000	38.34	0.0001
TIME	-2.30000000	0.67378639	79.35000000	11.65	0.0012

BOUNDS ON CONDITION NUMBER: 1, 9

THE ABOVE MODEL IS THE BEST 3 VARIABLE MODEL FOUND.

STEPWISE REGRESSION ANALYSIS

MAXIMUM R-SQUARE IMPROVEMENT FOR DEPENDENT VARIABLE FLOW

STEP 4 VARIABLE FITI ENTERED R SQUARE = 0.56492121 C(P) = 2.52638599

	DF	SUM OF SQUARES	MEAN SQUARE	F	PROB>F
REGRESSION	4	467.85833333	116.96458333	17.85	0.0001
ERROR	55	360.32500000	6.55136364		
TOTAL	59	828.18333333			

	B VALUE	STD ERROR	TYPE II SS	F	PROB>F
INTERCEPT	23.50000000				
FINE2	-0.31388889	0.07788503	106.40833333	16.24	0.0002
ASPH	1.47500000	0.23365508	261.07500000	39.85	0.0001
TIME	-2.30000000	0.66087637	79.35000000	12.11	0.0010
FITI	0.48333333	0.26980165	21.02500000	3.21	0.0787

BOUNDS ON CONDITION NUMBER: 1, 16

THE ABOVE MODEL IS THE BEST 4 VARIABLE MODEL FOUND.

STEP 5 VARIABLE FIAS ENTERED R SQUARE = 0.57290556 C(P) = 3.56244864

	DF	SUM OF SQUARES	MEAN SQUARE	F	PROB>F
REGRESSION	5	474.47083333	94.89416667	14.49	0.0001
ERROR	54	353.71250000	6.55023148		
TOTAL	59	828.18333333			

	B VALUE	STD ERROR	TYPE II SS	F	PROB>F
INTERCEPT	23.50000000				
FINE2	-0.31388889	0.07787830	106.40833333	16.24	0.0002
ASPH	1.47500000	0.23363489	261.07500000	39.86	0.0001
TIME	-2.30000000	0.66081926	79.35000000	12.11	0.0010
FIAS	0.09583333	0.09538104	6.61250000	1.01	0.3195
FITI	0.48333333	0.26977833	21.02500000	3.21	0.0788

BOUNDS ON CONDITION NUMBER: 1, 25

THE ABOVE MODEL IS THE BEST 5 VARIABLE MODEL FOUND.

STEPWISE REGRESSION ANALYSIS

MAXIMUM R-SQUARE IMPROVEMENT FOR DEPENDENT VARIABLE FLOW

STEP 6 VARIABLE ASPH2 ENTERED R SQUARE = 0.57607514 C(P) = 5.17978920

	DF	SUM OF SQUARES	MEAN SQUARE	F	PROB>F
REGRESSION	6	477.09583333	79.51597222	12.00	0.0001
ERROR	53	351.08750000	6.62429245		
TOTAL	59	828.18333333			

	B VALUE	STD ERROR	TYPE II SS	F	PROB>F
INTERCEPT	23.75000000				
FINE2	-0.31388889	0.07831733	106.40833333	16.06	0.0002
ASPH	1.47500000	0.23495199	261.07500000	39.41	0.0001
ASPH2	-0.12500000	0.19857067	2.62500000	0.40	0.5317
TIME	-2.30000000	0.66454458	79.35000000	11.98	0.0011
FIAS	0.09583333	0.09591875	6.61250000	1.00	0.3223
FITI	0.48333333	0.27129919	21.02500000	3.17	0.0806

BOUNDS ON CONDITION NUMBER: 1, 36

THE ABOVE MODEL IS THE BEST 6 VARIABLE MODEL FOUND.

STEP 7 VARIABLE ASTI ENTERED R SQUARE = 0.57729267 C(P) = 7.03279938

	DF	SUM OF SQUARES	MEAN SQUARE	F	PROB>F
REGRESSION	7	478.10416667	68.30059524	10.15	0.0001
ERROR	52	350.07916667	6.73229167		
TOTAL	59	828.18333333			

	B VALUE	STD ERROR	TYPE II SS	F	PROB>F
INTERCEPT	23.75000000				
FINE2	-0.31388889	0.07895317	106.40833333	15.81	0.0002
ASPH	1.47500000	0.23685952	261.07500000	38.78	0.0001
ASPH2	-0.12500000	0.20018283	2.62500000	0.39	0.5351
TIME	-2.30000000	0.66993988	79.35000000	11.79	0.0012
FIAS	0.09583333	0.09669749	6.61250000	0.98	0.3262
FITI	0.48333333	0.27350181	21.02500000	3.12	0.0831
ASTI	0.18333333	0.47371903	1.00833333	0.15	0.7003

BOUNDS ON CONDITION NUMBER: 1, 49

THE ABOVE MODEL IS THE BEST 7 VARIABLE MODEL FOUND.

TUCKER-NASER ASPHALT STUDY

MAXIMUM R-SQUARE IMPROVEMENT FOR DEPENDENT VARIABLE FLOW

STEP 8 VARIABLE FINE ENTERED R SQUARE = 0.57756435 C(P) = 9.00000000

	DF	SUM OF SQUARES	MEAN SQUARE	F	PROB>F
REGRESSION	8	478.32916667	59.79114583	8.72	0.0001
ERROR	51	349.85416667	6.85988562		
TOTAL	59	828.18333333			

	B VALUE	STD ERROR	TYPE II SS	F	PROB>F
INTERCEPT	23.75000000				
FINE	0.02500000	0.13804071	0.22500000	0.03	0.8570
FINE2	-0.31388889	0.07969784	106.40833333	15.51	0.0003
ASPH	1.47500000	0.23909352	261.07500000	38.06	0.0001
ASPH2	-0.12500000	0.20207091	2.62500000	0.38	0.5389
TIME	-2.30000000	0.67625861	79.35000000	11.57	0.0013
FIAS	0.09583333	0.09760952	6.61250000	0.96	0.3308
FITI	0.48333333	0.27608142	21.02500000	3.06	0.0860
ASTI	0.18333333	0.47818705	1.00833333	0.15	0.7030

BOUNDS ON CONDITION NUMBER: 1, 64

THE ABOVE MODEL IS THE BEST 8 VARIABLE MODEL FOUND.

STEPWISE REGRESSION ANALYSIS

MAXIMUM R-SQUARE IMPROVEMENT FOR DEPENDENT VARIABLE STAB

STEP 1 VARIABLE ASPH ENTERED R SQUARE = 0.32528185 C(P) = 465.22389217

	DF	SUM OF SQUARES	MEAN SQUARE	F	PROB>F
REGRESSION	1	5008173.43590083	5008173.43590083	27.96	0.0001
ERROR	58	10388238.89463280	179107.56714884		
TOTAL	59	15396412.33053370			

	B VALUE	STD ERROR	TYPE II SS	F	PROB>F
INTERCEPT	1627.26666667				
ASPH	-204.29091667	38.63370367	5008173.43590083	27.96	0.0001

BOUNDS ON CONDITION NUMBER: 1, 1

THE ABOVE MODEL IS THE BEST 1 VARIABLE MODEL FOUND.

STEP 2 VARIABLE TIME ENTERED R SQUARE = 0.63892005 C(P) = 224.93646582

	DF	SUM OF SQUARES	MEAN SQUARE	F	PROB>F
REGRESSION	2	9837076.53084084	4918538.26542042	50.43	0.0001
ERROR	57	5559335.79969281	97532.20701215		
TOTAL	59	15396412.33053370			

	B VALUE	STD ERROR	TYPE II SS	F	PROB>F
INTERCEPT	1627.26666667				
ASPH	-204.29091667	28.50909314	5008173.43590083	51.35	0.0001
TIME	567.38600000	80.63589234	4828903.09494002	49.51	0.0001

BOUNDS ON CONDITION NUMBER: 1, 4

THE ABOVE MODEL IS THE BEST 2 VARIABLE MODEL FOUND.

STEP 3 VARIABLE FINE ENTERED R SQUARE = 0.81339927 C(P) = 92.15019983

	DF	SUM OF SQUARES	MEAN SQUARE	F	PROB>F
REGRESSION	3	12523430.61384330	4174476.87128111	81.37	0.0001
ERROR	56	2872981.71669031	51303.24494090		
TOTAL	59	15396412.33053370			

	B VALUE	STD ERROR	TYPE II SS	F	PROB>F
INTERCEPT	1627.26666667				
FINE	86.38341667	11.93771392	2686354.08300250	52.36	0.0001
ASPH	-204.29091667	20.67672704	5008173.43590083	97.62	0.0001
TIME	567.38600000	58.48261562	4828903.09494002	94.12	0.0001

BOUNDS ON CONDITION NUMBER: 1, 9

THE ABOVE MODEL IS THE BEST 3 VARIABLE MODEL FOUND.

STEPWISE REGRESSION ANALYSIS

MAXIMUM R-SQUARE IMPROVEMENT FOR DEPENDENT VARIABLE STAB

STEP 4 VARIABLE FIAS ENTERED R SQUARE = 0.85527403 C(P) = 61.80169775

	DF	SUM OF SQUARES	MEAN SQUARE	F	PROB>F
REGRESSION	4	13168151.57256330	3292037.89314084	81.26	0.0001
ERROR	55	2228260.75797031	40513.83196310		
TOTAL	59	15396412.33053370			

	B VALUE	STD ERROR	TYPE II SS	F	PROB>F
INTERCEPT	1627.26666667				
FINE	86.38341667	10.60841280	2686354.08300250	66.31	0.0001
ASPH	-204.29091667	18.37430996	5008173.43590083	123.62	0.0001
TIME	567.38600000	51.97039668	4828903.09494002	119.19	0.0001
FIAS	-29.92400000	7.50128063	644720.95872000	15.91	0.0002

BOUNDS ON CONDITION NUMBER: 1, 16

THE ABOVE MODEL IS THE BEST 4 VARIABLE MODEL FOUND.

STEP 5 VARIABLE ASPH2 ENTERED R SQUARE = 0.89431350 C(P) = 33.64346894

	DF	SUM OF SQUARES	MEAN SQUARE	F	PROB>F
REGRESSION	5	13769219.34829250	2753843.86965850	91.39	0.0001
ERROR	54	1627192.98224114	30133.20337484		
TOTAL	59	15396412.33053370			

	B VALUE	STD ERROR	TYPE II SS	F	PROB>F
INTERCEPT	1507.63750000				
FINE	86.38341667	9.14895309	2686354.08300250	89.15	0.0001
ASPH	-204.29091667	15.84645159	5008173.43590083	166.20	0.0001
ASPH2	59.81458333	13.39269599	601067.77572917	19.95	0.0001
TIME	567.38600000	44.82053352	4828903.09494002	160.25	0.0001
FIAS	-29.92400000	6.46928677	644720.95872000	21.40	0.0001

BOUNDS ON CONDITION NUMBER: 1, 25

THE ABOVE MODEL IS THE BEST 5 VARIABLE MODEL FOUND.

STEPWISE REGRESSION ANALYSIS

MAXIMUM R-SQUARE IMPROVEMENT FOR DEPENDENT VARIABLE STAB

STEP 6 VARIABLE FITI ENTERED R SQUARE = 0.91456449 C(P) = 19.99945497

	DF	SUM OF SQUARES	MEAN SQUARE	F	PROB>F
REGRESSION	6	14081011.95181500	2346835.32530250	94.56	0.0001
ERROR	53	1315400.37871864	24818.87507016		
TOTAL	59	15396412.33053370			

	B VALUE	STD ERROR	TYPE II SS	F	PROB>F
INTERCEPT	1507.63750000				
FINE	86.38341667	8.30309097	2686354.08300250	108.24	0.0001
ASPH	-204.29091667	14.38137542	5008173.43590083	201.79	0.0001
ASPH2	59.81458333	12.15448062	601067.77572917	24.22	0.0001
TIME	567.38600000	40.67667232	4828903.09494002	194.57	0.0001
FIAS	-29.92400000	5.87117193	644720.95872000	25.98	0.0001
FITI	58.85883333	16.60618194	311792.60352250	12.56	0.0008

BOUNDS ON CONDITION NUMBER: 1, 36

THE ABOVE MODEL IS THE BEST 6 VARIABLE MODEL FOUND.

STEP 7 VARIABLE FINE2 ENTERED R SQUARE = 0.92965720 C(P) = 10.34023951

	DF	SUM OF SQUARES	MEAN SQUARE	F	PROB>F
REGRESSION	7	14313385.63491590	2044769.37641655	98.18	0.0001
ERROR	52	1083026.69561779	20827.43645419		
TOTAL	59	15396412.33053370			

	B VALUE	STD ERROR	TYPE II SS	F	PROB>F
INTERCEPT	1419.62733333				
FINE	86.38341667	7.60618105	2686354.08300250	128.98	0.0001
FINE2	14.66836111	4.39143068	232373.68310085	11.16	0.0016
ASPH	-204.29091667	13.17429203	5008173.43590083	240.46	0.0001
ASPH2	59.81458333	11.13430896	601067.77572917	28.86	0.0001
TIME	567.38600000	37.26252492	4828903.09494002	231.85	0.0001
FIAS	-29.92400000	5.37838220	644720.95872000	30.96	0.0001
FITI	58.85883333	15.21236210	311792.60352250	14.97	0.0003

BOUNDS ON CONDITION NUMBER: 1, 49

THE ABOVE MODEL IS THE BEST 7 VARIABLE MODEL FOUND.

STEPWISE REGRESSION ANALYSIS

MAXIMUM R-SQUARE IMPROVEMENT FOR DEPENDENT VARIABLE STAB

STEP 8 VARIABLE ASTI ENTERED R SQUARE = 0.93398110 C(P) = 9.00000000

	DF	SUM OF SQUARES	MEAN SQUARE	F	PROB>F
REGRESSION	8	14379958.18945670	1797494.77368209	90.19	0.0001
ERROR	51	1016454.14107695	19930.47335445		
TOTAL	59	15396412.33053370			

	B VALUE	STD ERROR	TYPE II SS	F	PROB>F
INTERCEPT	1419.62733333				
FINE	86.38341667	7.44059312	2686354.08300250	134.79	0.0001
FINE2	14.66836111	4.29582844	232373.68310085	11.66	0.0013
ASPH	-204.29091667	12.88748532	5008173.43590083	251.28	0.0001
ASPH2	59.81458333	10.89191305	601067.77572917	30.16	0.0001
TIME	567.38600000	36.45131306	4828903.09494002	242.29	0.0001
FIAS	-29.92400000	5.26129385	644720.95872000	32.35	0.0001
FITI	58.85883333	14.88118624	311792.60352250	15.64	0.0002
ASTI	47.10716667	25.77497065	66572.55454083	3.34	0.0735

BOUNDS ON CONDITION NUMBER: 1, 64

THE ABOVE MODEL IS THE BEST 8 VARIABLE MODEL FOUND.